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# LEHIGH UNIVERSITY



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AIRCRAFT MODEL PROTOTYPES WHICH HAVE SPECIFIED HANDLING-QUALITY TIME HISTORIES

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### ABSTRACT

Several techniques for obtaining linear constant-coefficient airplane models from specified handling-quality time histories are discussed. One technique, the pseudodata method, solves the basic problem, yields specified eigenvalues, and accommodates state-variable transfer-function zero suppression. The algebraic equations to be solved are bilinear, at worst. The disadvantages are reduced generality and no assurance that the resulting model will be airplanelike in detail.

The method is fully illustrated for a fourth-order stability-axis small-motion model with three lateral handling-quality time histories specified.

The Fortran program which obtains and verifies the model is included and fully documented.

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### SYMBOLS

vector containing all of the elements of A a plant matrix with elements aii input distribution vector with elements b; Ē coefficients matrix with elements  $c_{ij}$ final-value vector with elements c; normalized longitudinal handling-quality criterion C\*(t) longitudinal handling-quality criterion D( ) denominator polynomial D\* normalized lateral handling-quality criterion D\*(t) lateral handling-quality criterion differential operator  $d \equiv \frac{d()}{dt}$ d output measurement matrix, matrix transfer function Ğ augmented output measurement vector matrix þ input/output coupling vector ĥ augmented input/output coupling vector pilot station to vehicle C.G. distance ዩ N( ) numerator polynomials vector normalized roll-rate handling-quality time history P<sub>n</sub> p(t) roll rate cross-over dynamic pressure in D\* definition qco yaw rate r(t)Laplace transformation variable S similarity transformation matrix forcing function u(t)

```
nominal airspeed
٧
       state vector with elements x_{i}(t)
       output vector with elements y_{i}(t)
У
       specified response vector with elements \hat{\textbf{y}}_{i}(\textbf{t})
ŷ
ỹ
       augmented output vector
       normalized sideslip handling-quality time history
\beta_n
β(t)
       sideslip
       aileron deflection
\delta_{\mathbf{a}}
       elevator deflection
δε
       eigenmatrix
Â
       specified eigenmatrix
       eigenvalue vector with elements \lambda_{j}
λ
```

 $\phi(t)$ 

roll angle 🕆

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5	acceptable eigenvalues for second-order longitudinal models
6	fitted roll-rate and roll-acceleration responses
7	fitted sideslip and sideslip rate-of-change responses
8A,B	fitted $D_n^*$ and $D_n^*$ rate-of-change responses
9	roll-rate pseudodata
10	roll-rate response of fourth-order model
11	sideslip response of fourth-order model
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13	fitted roll rate with one zero suppressed
14	fitted roll rate with two zeros suppressed
15	fitted sideslip with one zero suppressed
16	fitted sideslip with two zeros suppressed
17	model roll rate and roll acceleration
18	model sideslip and sideslip rate-of-change
19A,B	model $D_n^*$ and $D_n^*$ rate-of-change
Al	program AANDB structure
A2	model roll rate and roll acceleration
А3	model sideslip and sideslip rate-of-change
A4A,B	model $D_n^*$ and $D_n^*$ rate-of-change

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### INTRODUCTION

Aircraft control systems have been designed in the past to meet stability, apparent damping, and sensitivity criteria. Subsequently, pilot comments and ratings, using the Cooper-Harper rating scale, graded the performance of the pilot-airplane-flight-control-system combination. The C-H scale emphasizes

**TAKEOFF** 

CRUISE

GROSS MANEUVERING AND AEROBATICS

FORMATION FLIGHT

TRACKING

GROUND-CONTROLLED APPROACH

LANDING APPROACH [1]\*

Experience has shown that the design criteria are often a subset of the handling-quality criteria. In order to design flight-control systems which achieve low (desirable) C-H ratings, some explicit consideration of handling qualities must be incorporated into the design process. The work begun by the Boeing Airplane Company and extended by the McDonnell-Douglas Company has resulted in quantitative specifications which are intended to insure "good" aircraft handling qualities. These specifications take the form of envelopes within which selected time-histories must fall,  $\underline{e}.\underline{g}.$ , normalized sideslip, normalized roll rate, and two blended quantities,  $C^*$  and  $D^*$ , containing the acceleration cues at the pilot station.

An evolutionary process has provided the basic design of most aircraft control systems. It is often the case that the selection of numerical values

The numbers in square brackets refer to bibliography entries.

for the many parameters in a control system is more difficult than the establishment of the control system structure and modes of operation. To overcome this "tuning" problem, a model-matching optimization technique can be implemented on a large digital computer. Such a program adjusts specified parameters of a simulated airplane-flight-control-system combination so as to minimize some measure of the dynamic differences between the closed-loop airplane and a low-order model of a desirable prototype airplane. As a participant in the ASEE-NASA Summer Faculty Fellowship Program in the summers of 1974 and 1975, the principal investigator, working in the Vehicle Dynamics and Control Division of the NASA Flight Research Center, Edwards, California, developed a method of translating handling-quality time-history specifications into prototype aircraft models. These models are suitable for subsequent use with an FRC model-matching program: CONOPT.

The connection between specified time histories which fall within the established envelopes and numerical values for adjustable parameters onboard the aircraft is, <u>in principle</u>, established. The method is explained in the following sections and the lateral-motion case demonstrated.

### PROBLEM STATEMENT

The NASA Flight Research Center computer program CONOPT, which resulted from the addition of the MIT Model Performance Index Design Program OPT to the in-house control system analysis program CONTROL, is a model-matching package. The user specifies the model in transfer-function form. The Model PI technique [2] requires that the model transfer function, if it has any zeros, should have the same number of excess poles over zeros as the closed-loop

airplane control system. If it has no zeros then the number of poles of the model transfer function should be equal to or less than the number of excess poles over zeros of the closed-loop airplane. Another condition on the model transfer function is that it must have reasonable eigenvalues. Thus the model is a linear, constant-coefficient ordinary differential equation in operator notation,

$$D(d)x(t) = N(d)u(t) , \qquad (1)$$

with loose bounds on the boots of,

$$D(\lambda_i) = 0 , \qquad (2)$$

and constraints on the coefficients of N(d). In order to obtain the entire matrix transfer function in one operation the model will be represented in state variable form,

$$d\underline{x} = \underline{A}\underline{x} + \underline{b}\underline{u} . \tag{3}$$

The problem is to determine an  $\underline{A}$  and  $\underline{b}$  combination which satisfies the loose bounds and constraints above and which describes a low-order prototype air-plane model with "good" handling qualities. FRC program CONTROL can be used to obtain transfer functions from  $\underline{A}$  and  $\underline{b}$  for use by CONOPT.

The handling-quality time histories,  $y_i(t)$ , are linear combinations of state variables,

$$y(t) = Gx(t) . (4)$$

If all the  $y_i(t)$  fall within their handling-quality time-history envelopes the model is appropriate for use with CONOPT.

The rigid-body equations of motion for symmetrical airplanes slightly disturbed from straight and level flight can be separated into two sets of four simultaneous first-order linear constant-coefficient ordinary differential equations [3]. One set describes the longitudinal motion, or motion in the plane of symmetry of a normally configured airplane. The other set describes the lateral motion. In each case,

$$dx = Ax + bu , (5)$$

where A is  $4 \times 4$  and b is  $4 \times 1$  if there is only one input.

Only one longitudinal handling-quality criterion has been established:  $C_n^{\star}$ . Three lateral handling-quality criteria have been proposed:  $D_n^{\star}$ , normalized roll rate, and normalized sideslip. An envelope for the first derivative of each handling-quality time history has also been proposed [4]. These eight envelopes are plotted in Figures 1 through 4. These handling-quality time-history envelopes imply standard inputs. The  $C_n^{\star}$  response results from a step change in elevator position,  $\delta_{\epsilon}$ , and the lateral handling-quality time responses result from a step change in aileron position,  $\delta_{a}$ .

### **METHODS**

An obvious procedure for obtaining models with handling-quality time histories which fall within specified envelopes is to:

- 1. Guess a model in terms of  $\underline{A}$  and  $\underline{b}$
- Calculate x(t)
- 3. Form y(t)
- 4. Compare  $\underline{y}(t)$  and  $\underline{\mathring{y}}(t)$  to the appropriate envelopes

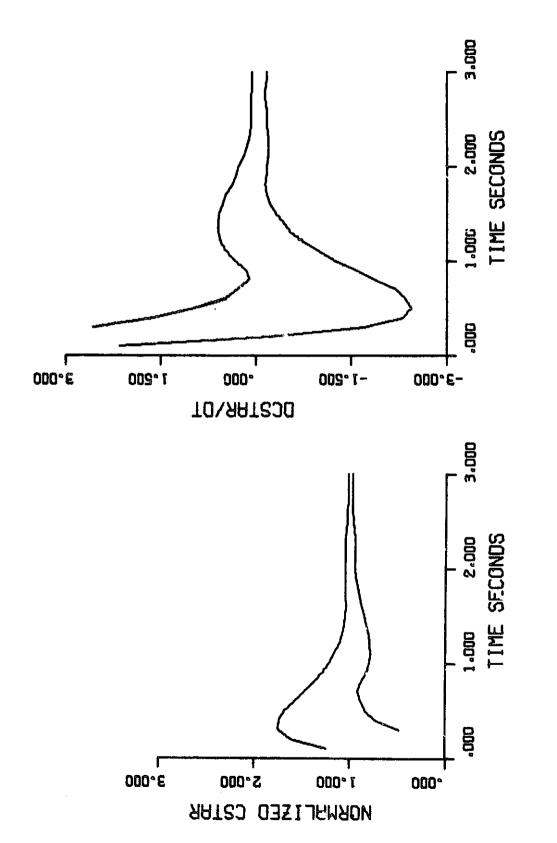


FIG.1 LONG. CRIT. ENVELOPES

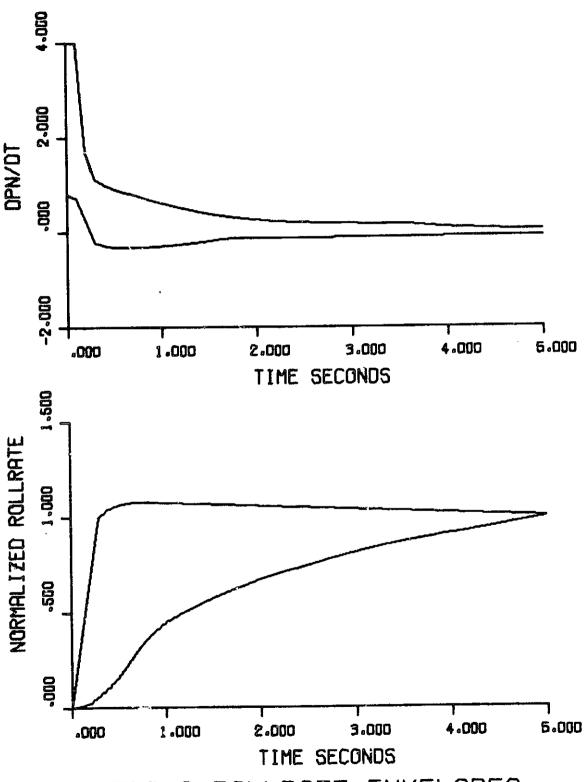
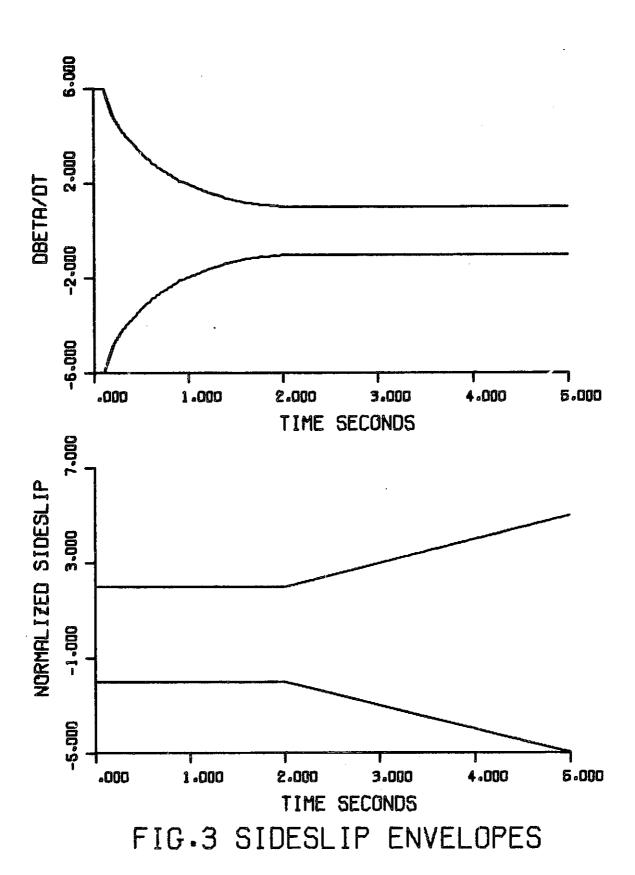


FIG.2 ROLLRATE ENVELOPES



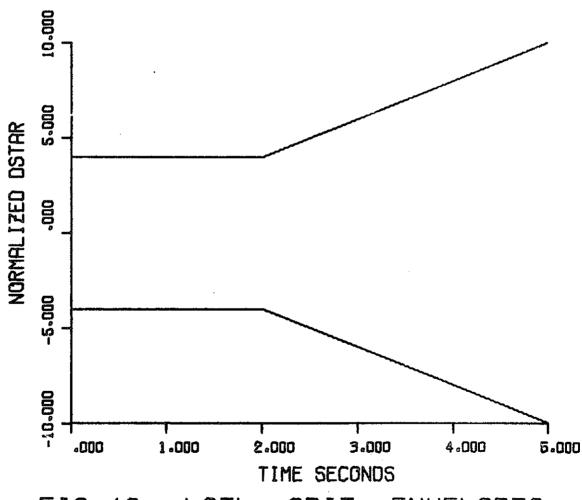


FIG.4A LATL. CRIT. ENVELOPES

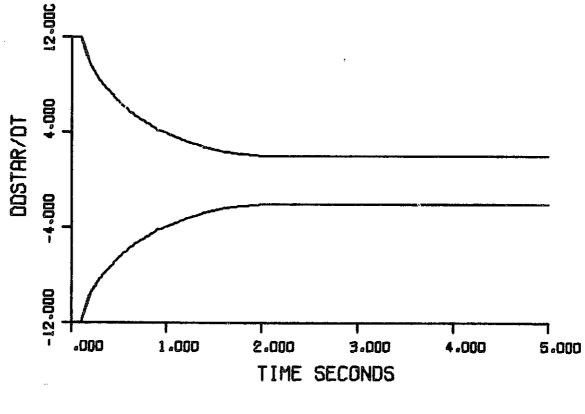


FIG. 4B

- 5. If no envelopes are violated, stop
- Otherwise alter A and/or b according to some strategy and return to Step 2.

This "brute force" technique would consume large amounts of computer time and may not succeed. It would be necessary to define a cost functional which measures all excursions outside of the envelopes and which is suitable for use in a numerical optimization scheme. Next a connection between the elements  $a_{ij}$  and  $b_i$  and the cost functional would have to be established. Finally, there is no assurance that the attainable minima of this functional would be zero. The addition of hard and soft constraints arising from the loose bounds on the eigenvalues and specification of the pole-zero excess of the transfer functions complicates the numerical optimization problem. In the fourth-order lateral-motion case there would be: twelve variables to be manipulated, four soft constraint equations to be approximately satisfied, n hard constraint equations where n is the sum of the specified pole-zero excesses, and six envelopes to be matched.

One simplification which circumvents the need for a cost functional and optimization strategy is the use of direct search. If any solution which satisfies the constraints and the envelopes is as useful as any other, systematic or random direct search is easier to implement and no more wasteful of computer time than optimization. Random direct search has been used to obtain second-order longitudinal airplane transfer functions. In this simpler situation the  $a_{ij}:i,j=1,2$  are randomly selected. If the resulting eigenvalues fall within the region shown in Figure 5 [4], the  $b_i:i=1,2$  are randomly selected and  $C^*$  and  $C^*$  calculated. The ranges of the random choices are very

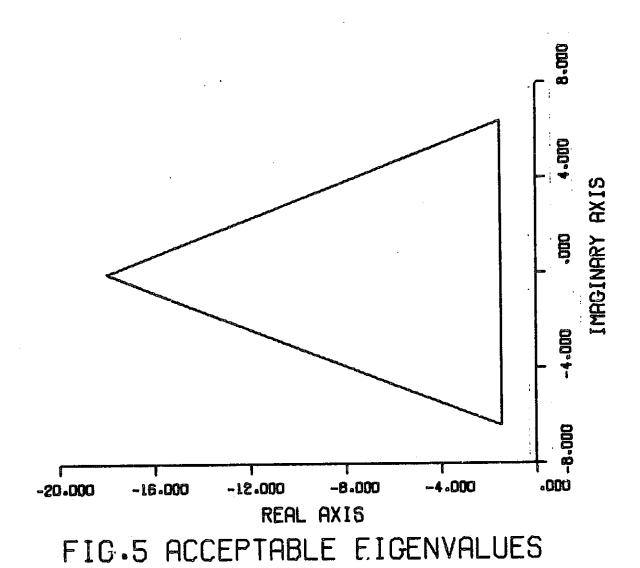
### influential. Sample results are:

- 1. 558 random sets of  $a_{ij}$  yielded 22 acceptable pairs of real eigenvalues and six acceptable pairs of complex eigenvalues.
- 2. For A having acceptable real eigenvalues 118 random pairs of.  $b_{i} \ \ \text{were required to find one pair which yielded time-responses}$  which match the C\* and C\* envelopes.
- 3. For  $\underline{A}$  having acceptable complex eigenvalues 320 random pairs of  $\mathbf{b_i}$  were required to find one pair which satisfied the envelopes.
- 4. If one envelope was matched (and the other violated) it was as likely to be the  $\mathring{\mathbb{C}}^*$  envelope as the  $\mathbb{C}^*$  envelope.

The application of direct search to the fourth-order problem is currently being investigated. This is potentially useful for the development of models which satisfy the longitudinal criteria,  $C^*$  and  $C^*$ , but less so for the lateral case. In order to develop lateral motion models <u>and</u> obviate the use of iterative numerical techniques the problem must be reposed.

If one begins with specific time responses which fall within the envelopes and seeks a model whose output responses closely resemble the specified handling-quality time histories the problem no longer requires iteration. If the eigenvalues are specified or obtained from the input responses and then frozen and if all elements of  $\underline{A}$  and  $\underline{b}$  are unspecified rather than just those elements which are normally nonzero for most airplanes, the problem is well-posed. This procedure has three disadvantages:

1. The partial degrees of freedom represented by loose bounds on



on the eigenvalues are lost.

- The envelopes are not directly used and may be violated by the results.
- 3. The resulting  $\underline{A}$  is not constrained to have the zero elements and kinematic elements usually found in such models of airplanes.

Experience with lateral-motion examples has shown that  $\underline{A}$  may well have obviously unrealistic elements and still produce realistic transfer functions. This is sufficient for present purposes.

The reposed problem is the following: given  $\hat{y}(t)$ ,  $h(a_{ij})$  and  $g(a_{ij})$ , find A and b such that if

$$d\underline{x} = \underline{A}\underline{x} + \underline{b}\delta_{a} , \qquad (6)$$

and if

$$\underline{y} = \underline{G}\underline{x} + \underline{h}\delta_{a} \quad , \tag{7}$$

then

$$\underline{y} \approx \hat{\underline{y}}$$
 in some best sense,

with

$$\bar{\Lambda} = \hat{\Lambda} \tag{8}$$

Note that the elements of  $\underline{G}$  and  $\underline{h}$  are known functions of the unknown elements of  $\underline{A}$  and that  $\underline{G}$  is normally not square, there being fewer elements in  $\underline{y}$  than in  $\underline{x}$ .

The first step is to obtain an analytical representation of the input time histories which one specifies in the form of a table of discrete values uniformly spaced in time. If the model is to be a fourth-order constant-

coefficient linear ordinary differential equation, its solution must have the form:

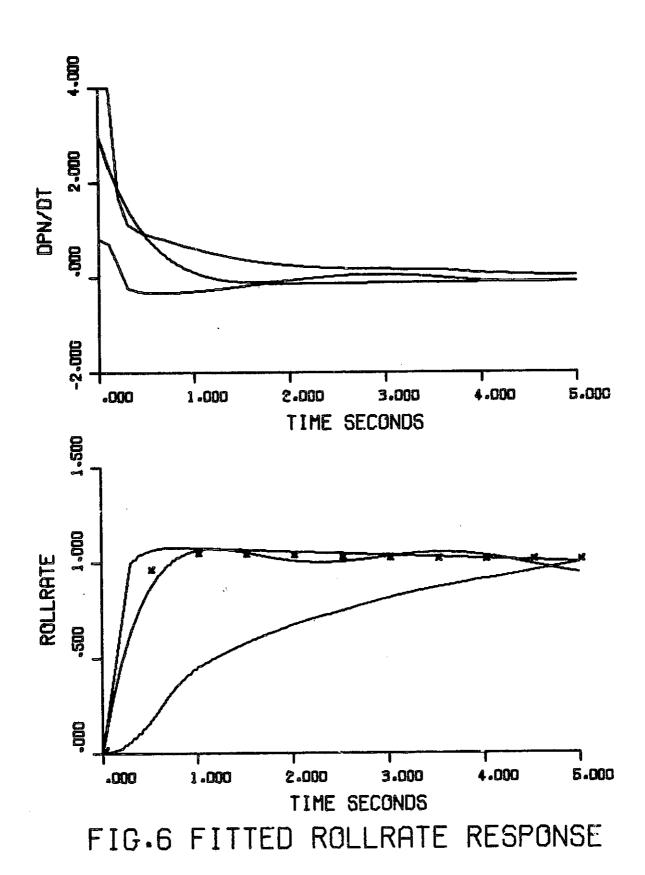
$$y_{i}(t) = c_{i1}e^{\lambda_{1}t} + c_{i2}e^{\lambda_{2}t} + c_{i3}e^{\lambda_{3}t} + c_{i4}e^{\lambda_{4}t} + c_{i}$$
 (9)

These coefficients and eigenvalues,  $c_{ij}$  and  $\lambda_j$ , are obtained by least-squared-error fitting the above form to the specified discrete values of  $\hat{y}_i$ . This is a two-step process. First the  $\lambda_j$  are calculated. The calculation is based upon first and second differences between adjacent  $\hat{y}_i$  values and is strongly influenced by their precision. If the values are represented by three significant figures the resulting eigenvalues are drastically incorrect even when the data are contrived and there should be an exact solution. As the number of significant figures is increased the calculated eigenvalues more closely resemble the correct values. However, if data obtained from sketched time responses or imprecise tables are to be accommodated, it is impractical to calculate eigenvalues from such data. In such cases, the eigenvalues which the model is to have must be specified. In either case, the  $c_{ij}$  are straightforwardly calculated and the resulting fits usually quite good. Thus one can represent the input time histories,  $\hat{y}(t)$ , as

$$\hat{y} \approx y = \underline{c}\underline{e}^{\lambda t} + \underline{c}$$
 (10)

where the elements of  $\underline{c}$  are the  $c_{\underline{i}}$ .

An example set of discrete input data points and their fitted representations is shown in Figures 6 through 8. Reasonable responses were sketched onto graphs of the lateral handling-quality envelopes and then converted to tabular form by estimating the values at half-second intervals. The eigenvalues used in the curve-fitting process were specified. The values used were:



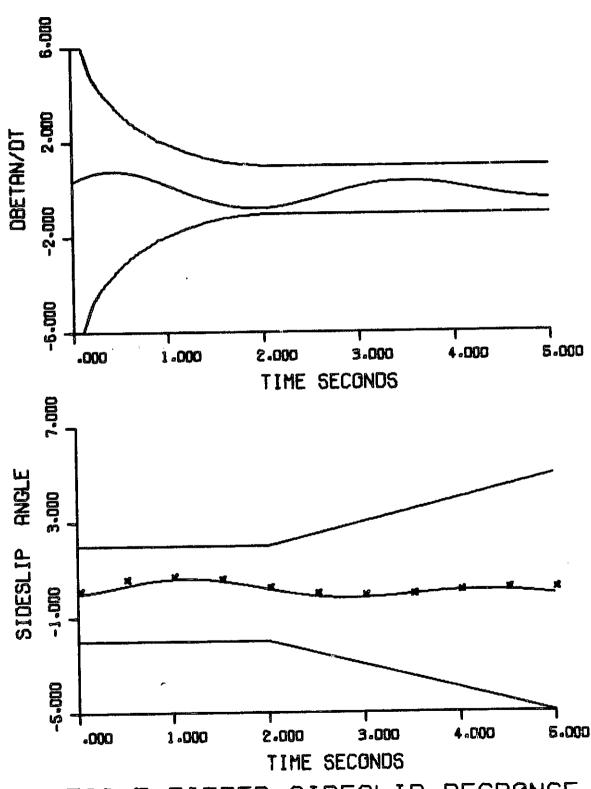
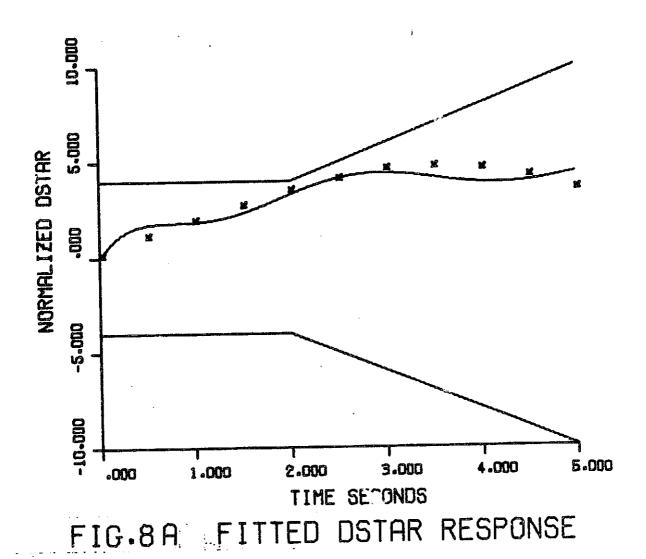


FIG.7 FITTED SIDESLIP RESPONSE



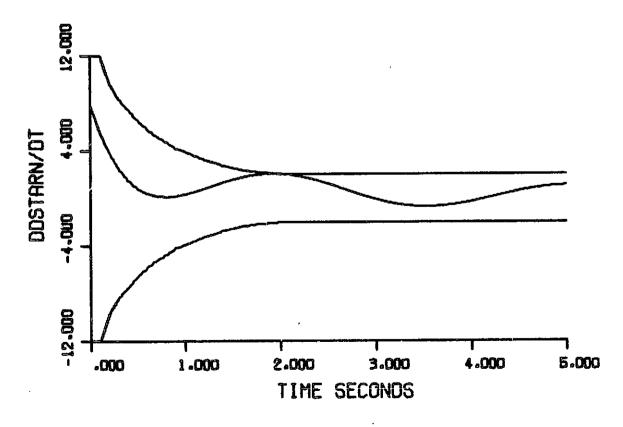


FIG. 8B

$$\lambda_1 = -2.4$$
 $\lambda_2 = -.003$ 
 $\lambda_3 = -.25 - j2.0$ 
 $\lambda_4 = -.25 + j2.0$ 

Once the specified discrete values of the  $\hat{y}_i$  are approximately represented

$$y = \underline{C}\underline{e}^{\underline{\lambda}t} + \underline{c}$$

This equation can be Laplace transformed into

$$\underline{Y}(s) = \frac{\underline{N}(s)}{\overline{D}(s)} . \tag{11}$$

Assuming a unit-step input, the plant and output equations can also be Laplace transformed into

$$s\underline{x}(s) = \underline{A}\underline{x}(s) + \underline{b}/s$$

$$\underline{Y}(s) = \underline{G}\underline{X}(s) + \underline{h}/s$$

which are manipulated to obtain

$$\underline{X}(s) = (s\underline{I} - \underline{A})^{-1}\underline{b}/s = \underline{\phi}(s)\underline{b}/s$$

$$\underline{Y}(s) = \underline{G}\underline{\phi}(s)\underline{b}/s + \underline{h}/s . \qquad (12)$$

If equation 12 is rearranged to match the form of equation 11, the right-hand sides of equations 11 and 12 can be equated, coefficient by coefficient, to produce n(m+1) simultaneous algebraic equations where n is the order of the plant equation, equation 6, and m is the number of elements in the output vector, equation 7. For low-order models this is a satisfactory technique.

The algebraic equations are of degree  $\leq n$ . In the fourth-order lateral-motion example there are sixteen nonlinear equations containing, at worst, quadruple-cross-product terms. A limited amount of experience with these equations has shown them to be numerically sensitive. An effort is being made to develop a computer program which will solve the fourth-order example equations with various constraints on the elements and eigenvalues of  $\underline{A}$ . While this may prove to be the most satisfactory approach to the problem, the numerical uncertainties are sufficient to motivate the development of an alternative technique which is computationally simpler.

A less numerically-sensitive approach can be developed by combining equations 7 and 10.

$$y = \underline{G}\underline{x} + \underline{h}\delta_{a}$$

$$\underline{x} = \underline{G}^{-1}\underline{y} - \underline{G}^{-1}\underline{h}\delta_{a}$$

$$\underline{x} = \underline{G}^{-1}\underline{C}\underline{e}^{\lambda t} + \underline{G}^{-1}\underline{c} - \underline{G}^{-1}\underline{h}\delta_{a}$$

$$d\underline{x} = \underline{G}^{-1}\underline{C}\underline{\Lambda}\underline{e}^{\lambda t} - \underline{G}^{-1}\underline{h}d\delta_{a}$$

If these expressions are substituted into equation 6 one obtains

$$\underline{G}^{-1}\underline{C}\underline{\Lambda}\underline{e}^{\lambda t} - \underline{G}^{-1}\underline{h}\underline{d}\underline{\delta}_{a} = \underline{A}\underline{G}^{-1}\underline{C}\underline{e}^{\lambda t} + \underline{A}\underline{G}^{-1}\underline{c} - \underline{A}\underline{G}^{-1}\underline{h}\delta_{a} + \underline{b}\delta_{a}$$

or

$$(\underline{G}^{-1}\underline{C}\underline{\Lambda} - \underline{A}\underline{G}^{-1}\underline{C})\underline{e}^{\underline{\lambda}t} = \underline{A}\underline{G}^{-1}\underline{c} + \underline{G}^{-1}\underline{h}d\delta_{a} + (\underline{b} - \underline{A}\underline{G}^{-1}\underline{h})\delta_{a} .$$

For this expression to be true

$$\underline{G}^{-1}\underline{C}\underline{\Lambda} = \underline{A}\underline{G}^{-1}\underline{C} \tag{13a}$$

and

$$(\underline{A}\underline{G}^{-1}\underline{h} - \underline{b})\delta_{a} = \underline{A}\underline{G}^{-1}\underline{c}$$
 (13b)

If  $\underline{T} = \underline{G}^{-1}\underline{C}$ , then

$$\underline{A} = \underline{T}\underline{\Lambda}\underline{T}^{-1} \tag{14}$$

and

$$b = AG^{-1}(\underline{h} - \underline{c}) . \tag{15}$$

It is assumed that  $\delta_a(t) \equiv 1$  and  $\underline{G}^{-1}\underline{h}d\delta_a$  is neglected at this point but must be introduced as an initial condition vector when computing model time responses. A model obtained from equations 14 and 15 will have the specified eigenvalues and match the <u>analytical representations</u> of the input data exactly.

Unfortunately the above results assume the existence of  $g^{-1}$  whereas, in general, g is not square. One can substitute the right pseudoinverse and obtain similar results except that g will be singular and the model eigenvalues are no longer equal to the specified eigenvalues since g and g are no longer similar. If g is square and nonsingular, equations 14 and 15 hold. There are two cases of practical interest in which g is nonsingular. First, one can specify g and g that is, let the number of time histories establish the order of the model. Secondly, it may be possible to adjoin created pseudo-time-histories to g until g and g are no longer time-histories. They must be linear combinations of the model state variables and the resulting distribution matrix must be nonsingular.

In the lateral-direction, small-motion example, the state variables are roll rate, yaw rate, sideslip angle and roll angle. The handling-quality indicators are normalized roll rate, normalized sideslip angle and normalized  $D^{\star}$ .

The normalized roll-rate input data can be integrated to produce normalized roll-angle pseudodata. For the example, this was accomplished by exactly fitting a tenth-order polynomial to the eleven discrete roll-rate data points shown in Figure 6. This polynomial was integrated and evaluated at the same values of time to generate the discrete pseudodata points shown in Figure 9. The continuous curve in Figure 9 results from fitting an equation of the form of equation 9 to the discrete pseudodata points just as is done for the normal data. This allows the expansion of y to  $\tilde{y}$  and  $\tilde{g}$  to  $\tilde{g}$  and assures the nonsingularity of  $\tilde{g}$ . This, in turn, allows calculation of A and b using equations 14 and 15. The same straightforward opportunity to augment y until  $\tilde{g}$  is square and nonsingular does not exist in the longitudinal small-motion case, although a designer could impose specifications on the motion, in addition to the Boeing C\* criterion, and thereby create a nonsingular  $\tilde{g}$ .

### COMPUTATIONAL PROCEDURES

p\* is a weighted combination of aircraft sideslip which is considered the principal low-speed handling-quality parameter and lateral acceleration at the pilot station which is the principal motion cue parameter at high speeds [4]. In terms of a stability-axis system representation of small perturbations about straight and level flight for a normally configured aircraft with the pilot station on the longitudinal principal axis the expression for D\* is

$$D^{*}(t) = V(\mathring{\beta} + r) + \ell \mathring{r} + c_{3}q_{CO}\beta$$
 (16)

where  $c_3$  is a dimensional constant defined in Table 1. In terms of the

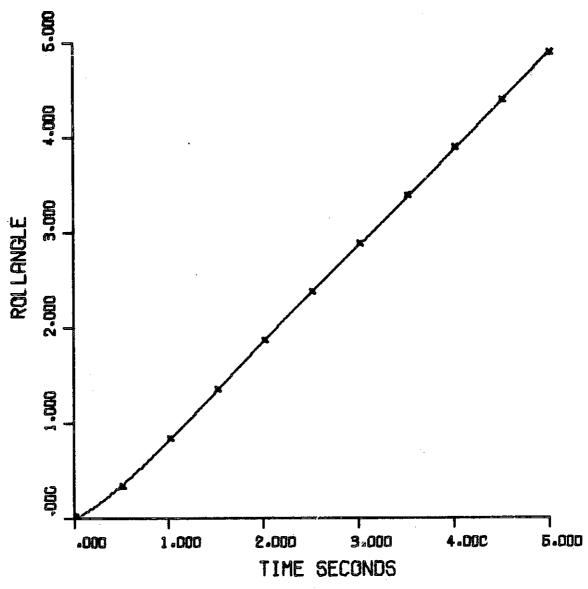


FIG.9 ROLLANGLE PSEUDODATA

elements  $\underline{\underline{A}}$  and  $\underline{\underline{b}}$  one obtains

$$D_{p} = Va_{31} + la_{21}$$

$$D_{r} = Va_{32} + la_{22} + V$$

$$D_{\beta} = Va_{33} + la_{23} + c_{3}q_{co}$$

$$D_{\phi} = Va_{34} + la_{24}$$

$$D_{\delta_{a}} = Vb_{3} + lb_{1}$$

and

$$D^{*}(t) = D_{p}p(t) + D_{r}r(t) + D_{\beta}\beta(t) + D_{\phi}\phi(t) + D_{\delta_{a}}\delta_{a} . \qquad (18)$$

Unit Correction Factors for  $D^{\star}$  Equation

D*	β	c <sub>3</sub>	
		Value	Units
g's	rad	-9.91 x 10 <sup>-3</sup>	$\left(\frac{g's - rt^2}{lb}\right)$
	deg	-1.73 x 10 <sup>-4</sup>	
ft/sec <sup>2</sup>	rad	-3.19 x 10 <sup>-1</sup>	$\left(\frac{\text{ft}^3}{\text{1b-sec}^2}\right)$
	deg	-5.57 x 10 <sup>-3</sup>	

Units for crossover dynamic pressure,  $q_{co}$ ;  $lb/ft^2$ 

Table 1 [4]

Note that this assumes that the plant matrix is

$$\underline{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots \\ a_{21} & \vdots & \vdots \end{bmatrix}$$

With no constraints on the elements  $a_{ij}$ . Thus  $\underline{A}$  is specifically not constrained to be of the form

$$\underline{A} = \begin{bmatrix} L_{p} & L_{r} & L_{\beta} & 0 \\ N_{p} & N_{r} & N_{\beta} & 0 \\ \alpha_{o} & -1 & Y_{\beta} & Y_{\phi} \\ 1 & 0 & 0 & 0 \end{bmatrix} , \qquad (19)$$

similarly

$$\underline{b} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \quad \text{and not} \quad \begin{bmatrix} L_{\delta a} \\ N_{\delta a} \\ v_{\delta a} \\ 0 \end{bmatrix}.$$

Thus the output distribution matrix  $\underline{G}$  for the lateral motion case is of the form

$$\underline{G} = \begin{bmatrix}
 1/p_{SS} & 0 & 0 & 0 \\
 0 & 0 & 1/\beta_{SS} & 0 \\
 D_p/D_{SS} & D_r/D_{SS} & D_{\beta}/D_{SS} & D_{\phi}/D_{SS}
\end{bmatrix}$$
(20)

where

$$y_1(t) = p(t)/p_{ss} = p_n(t)$$

$$y_2(t) = \beta(t)/\beta_{ss} = \beta_n(t)$$

$$y_3(t) = D^*(t)/D_{ss} = D_n^*(t)$$
 (21)

and

$$\underline{h} = \begin{bmatrix} 0 \\ 0 \\ D_{\delta_a}/D_{ss} \end{bmatrix}$$
(22)

The augmented output distribution matrix is

$$\tilde{\mathbf{G}} = \begin{bmatrix}
1/p_{ss} & 0 & 0 & 0 \\
0 & 0 & 1/\beta_{ss} & 0 \\
0 & 0 & 0 & 1/p_{ss} \\
D_p/D_{ss} & D_r/D_{ss} & D_{\beta}/D_{ss} & D_{\phi}/D_{ss}
\end{bmatrix}$$
(23)

which is nonsingular if  $D_r \neq 0$ . The augmented output vector,  $\underline{\tilde{y}}(t)$ , is

$$\widetilde{y}_{1}(t) = p_{n}(t)$$

$$\widetilde{y}_{2}(t) = \beta_{n}(t)$$

$$\widetilde{y}_{3}(t) = \int p_{n}(t)dt = \phi_{n}(t)$$

$$\widetilde{y}_{4}(t) = D_{n}^{*}(t)$$
(24)

Since  $n^2$  elements of A and the n elements of b are to be established equation 14 is equivalent to  $n^2$  scalar equations with  $n^2$  unknowns and equation 15 is equivalent to n scalar equations with n unknowns. This is not significantly different from the Laplace transform method in which one obtains n(m+1) algebraic equations without having had to create psuedodata. However, the degree

of the simultaneous equations to be solved in the Laplace transform method is n whereas the equations arising from the pseudodata method contain cross-product terms at worst. This dramatically increases the liklihood of obtaining solutions by iterative numerical means. For the fourth-order lateral motion example, there are sixteen equations to be solved for the  $a_{ij}$ . A Newton-Euler procedure [5] was employed in which an initial estimate of the solution vector  $\underline{a}$  is iteratively improved. If equation 14 is rewritten

$$\underline{\mathbf{f}}(\underline{\mathbf{a}}) = \underline{\mathbf{0}} \tag{25}$$

and  $P(\underline{a})$  is the Jacobian matrix associated with the equation 25 then

$$\underline{\mathbf{a}}_{k+1} = \underline{\mathbf{a}}_k - \underline{\mathbf{P}}^{-1}(\underline{\mathbf{a}}_k)\underline{\mathbf{f}}(\underline{\mathbf{a}}_k) \tag{26}$$

This simple procedure has proved to be so successful that  $\underline{A} = \underline{I}$  can be used as the starting point and every element of  $(\underline{a}_{k+1} - \underline{a}_k)$  is reduced to  $10^{-5}$  in three iterations typically. The elements of  $\underline{b}$  are obtained from equation 15 without iteration.

Before  $\underline{A}$  and  $\underline{b}$  can be calculated, equations of the form of equation 10 must be fitted to the input data. The resulting coefficient arrays  $\underline{C}$  and  $\underline{c}$  appear in equations 14 and 15. Note that  $\underline{T} = \widetilde{\underline{G}}^{-1}\underline{C}$  in the pseudodata method.

A set of eigenvalues can be obtained from each discretized input time history. If

$$e_z = y_i(z\Delta t) - \hat{y}_i(z\Delta t)$$

and

$$\mu_{\mathbf{j}} = e^{\lambda \mathbf{j}^{\Delta t}}$$

then

$$e_{z} = c_{i1}\mu_{1}^{z} + c_{i2}\mu_{2}^{z} + c_{i3}\mu_{3}^{z} + c_{i4}\mu_{4}^{z} + c_{i} - \hat{y}_{i}(z\Delta t)$$
 (27)

Where

$$z = 1,2,...$$
(number of discrete values  $\hat{y}_{i}(z\Delta t)$ ).

The  $c_{ij}$  and  $c_{i}$  can be eliminated by linearly combining the  $e_{z}$ . One obtains a linear set of simultaneous algebraic equations

$$\underline{\mathbf{p}}' \underline{\mathbf{\mu}} = \underline{\mathbf{d}}' \tag{28}$$

where the elements of D' are first differences of the table of  $\hat{y}_i(z\Delta t)$  values and the elements of <u>d</u>' are second differences. Unfortunately, if the  $\hat{y}_i(z\Delta t)$  values are obtained from time-response sketches or are imprecise for any reason the  $\mu_j$  calculated from equation 28 are uselsss. Frequently the  $\mu_j$  obtained in such cases have negative values from which no  $\lambda_j$  can be calculated.

In lieu of eiganvalues obtained from the input data, it has been necessary , in all practical calculations, to use specified eigenvalues. In such cases the calculation of  $\underline{C}$  is based on minimizing

$$E = \sum_{Z=1}^{11} e_Z^2$$

where the lateral handling-quality time histories typically span five seconds and are discretized by taking values every half second for a total of eleven values per time history. The initial value of  $\tilde{y}(t)$  is forced to be zero by

$$c_{\mathbf{i}} - \sum_{\mathbf{j}=1}^{4} c_{\mathbf{i}\mathbf{j}} . \tag{29}$$

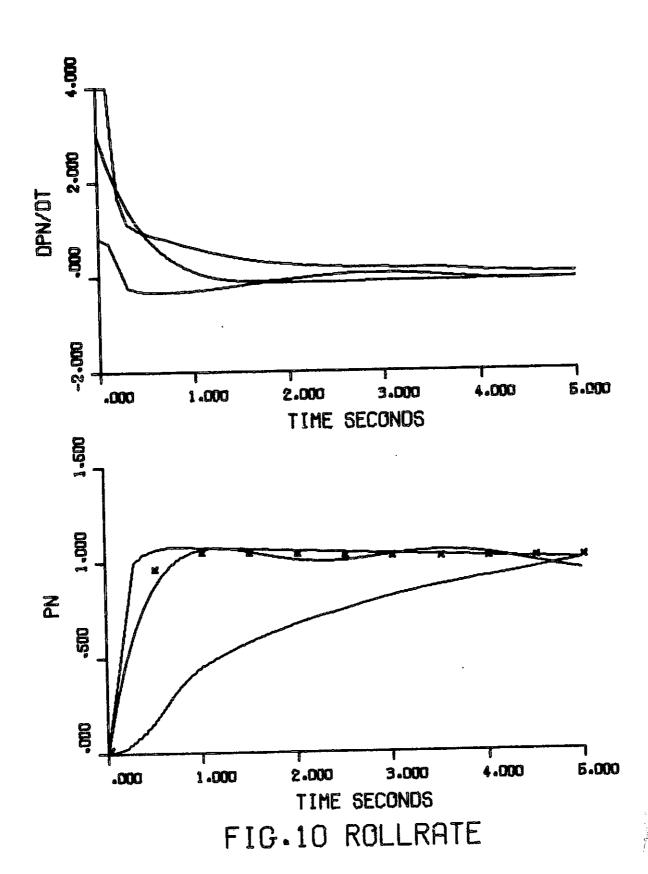
As a check on the entire computational process once an  $\underline{A}$  and  $\underline{b}$  have been

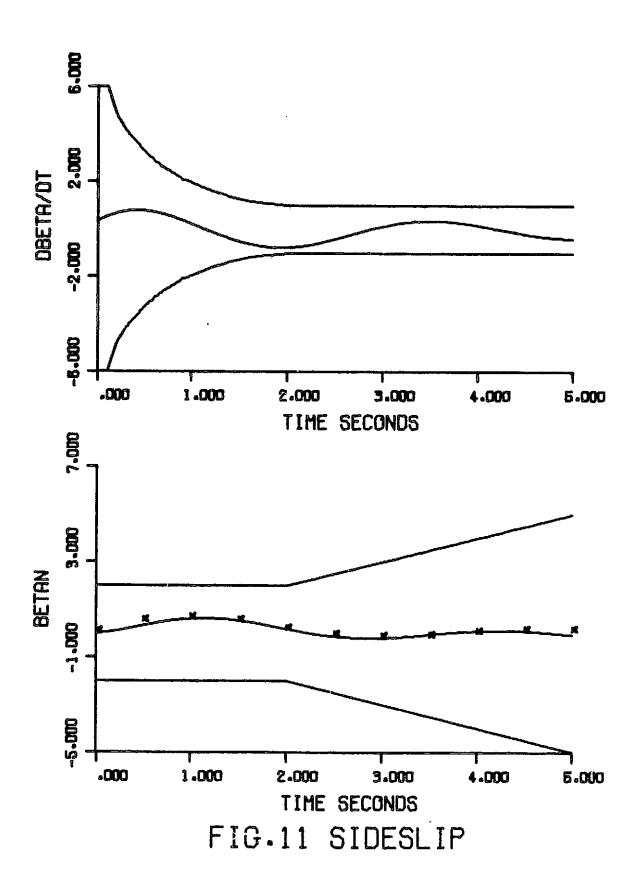
calculated,  $\underline{G}$  and  $\underline{h}$  can be calculated,  $\underline{x}(t)$  obtained by integration and  $\underline{y}(t)$  calculated. This  $\underline{y}(t)$ , obtained by integration, is plotted with the fitted  $\underline{y}(t)$ . They should be identical. The integration method is described in Takarashi,  $\underline{et}$ ,  $\underline{al}$ , page 103 [6]. The solution matrix is represented by a series expansion containing p terms. The number of terms is specified by a recipe attributed to Paynter

$$\frac{1}{p!} (nq)^p e^{nq} \approx 0.001$$
 (30)

where n is the size of the A matrix and q is the largest element of  $\underline{A}\Delta t$ .

The example fitted and integrated handling-quality time histories are plotted in Figures 10, 11, and 12.





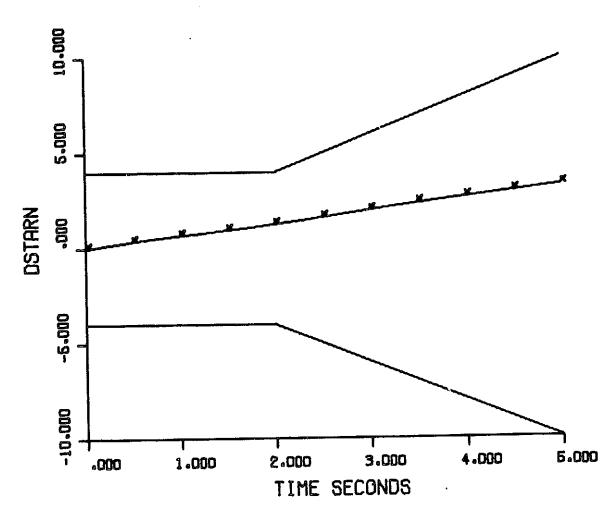


FIG.12 A LATERAL CRITERION

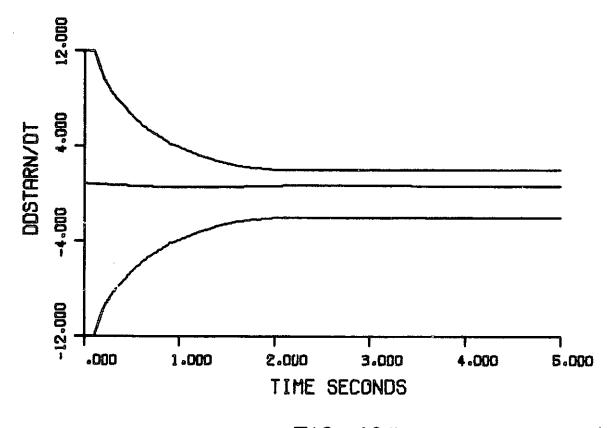


FIG. 12B

### ZERO SUPPRESSION

The Laplace-transformed analytical representation of the input data, equation 11, has one fewer zero than poles in each element of the matrix transfer function  $\underline{G}(s)$  where

$$Y(s) = G(s)/s$$

or

$$Y_{i}(s) = \frac{c_{i1}}{s-\lambda_{1}} + \frac{c_{i2}}{s-\lambda_{2}} + \frac{c_{i3}}{s-\lambda_{3}} + \frac{c_{i4}}{s-\lambda_{4}} + \frac{co_{i}}{s} .$$

This expression can be rewritten, omitting the i subscript

$$(c_{1}\lambda_{1} + c_{2}\lambda_{2} + c_{3}\lambda_{3} + c_{4}\lambda_{4})s^{3} - (c_{3}\lambda_{3}\lambda_{4} + c_{4}\lambda_{3}\lambda_{4} + c_{\lambda_{1}}\lambda_{3}$$

$$+ c_{3}\lambda_{1}\lambda_{3} + c_{1}\lambda_{1}\lambda_{4} + c_{4}\lambda_{1}\lambda_{4} + c_{2}\lambda_{2}\lambda_{3} + c_{2}\lambda_{2}\lambda_{4} + c_{4}\lambda_{2}\lambda_{4} + c_{1}\lambda_{2}\lambda_{1}$$

$$+ c_{2}\lambda_{1}\lambda_{2})s^{2} - (c_{1}\lambda_{1}\lambda_{3}\lambda_{4} + c_{3}\lambda_{1}\lambda_{3}\lambda_{4} + c_{4}\lambda_{1}\lambda_{3}\lambda_{4} + c_{4}\lambda_{1}\lambda_{3}\lambda_{4} + c_{2}\lambda_{2}\lambda_{3}\lambda_{4}$$

$$+ c_{3}\lambda_{2}\lambda_{3}\lambda_{4} + c_{2}\lambda_{2}\lambda_{3}\lambda_{4} + c_{1}\lambda_{1}\lambda_{2}\lambda_{3} + c_{2}\lambda_{1}\lambda_{2}\lambda_{3} + c_{3}\lambda_{1}\lambda_{2}\lambda_{3}$$

$$+ c_{1}\lambda_{1}\lambda_{2}\lambda_{4} + c_{2}\lambda_{1}\lambda_{2}\lambda_{4} + c_{4}\lambda_{1}\lambda_{2}\lambda_{4})s + \lambda_{1}\lambda_{2}\lambda_{3}\lambda_{4}$$

$$(31)$$

To reduce the number of zeros in the transfer function, the following constraint equations must be incorporated into the least-square minimization, equation 29. To suppress one zero

$$c_1 \lambda_1 + c_2 \lambda_2 + c_3 \lambda_3 + c_4 \lambda_4 = 0 . (32)$$

To suppress two zeros

$$c_1 \lambda_1 + c_2 \lambda_2 + c_3 \lambda_3 + c_4 \lambda_4 = 0$$

and

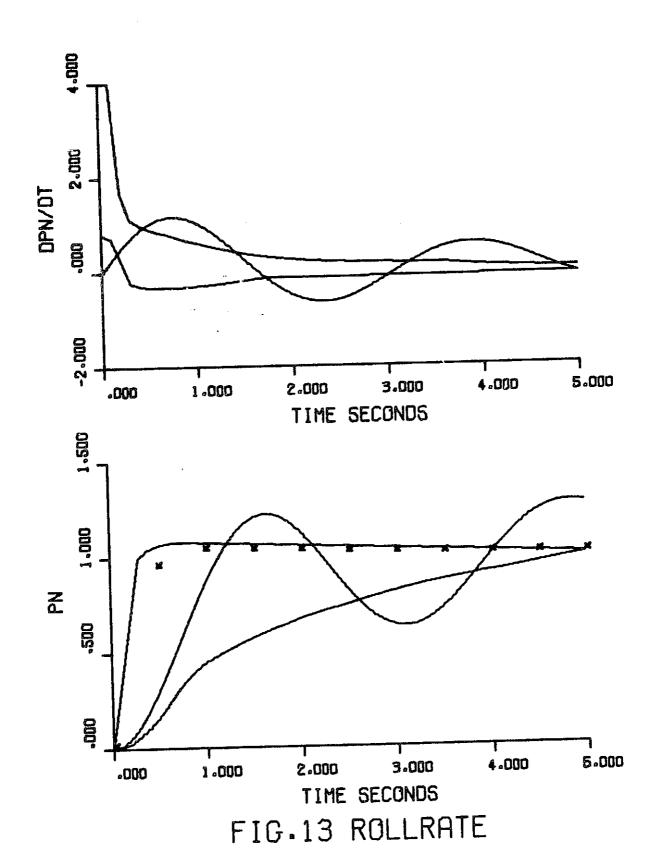
$$c_{3}\lambda_{3}\lambda_{4} + c_{4}\lambda_{3}\lambda_{4} + c_{1}\lambda_{1}\lambda_{3} + c_{3}\lambda_{1}\lambda_{3} + c_{1}\lambda_{1}\lambda_{4} + c_{4}\lambda_{1}\lambda_{4}$$

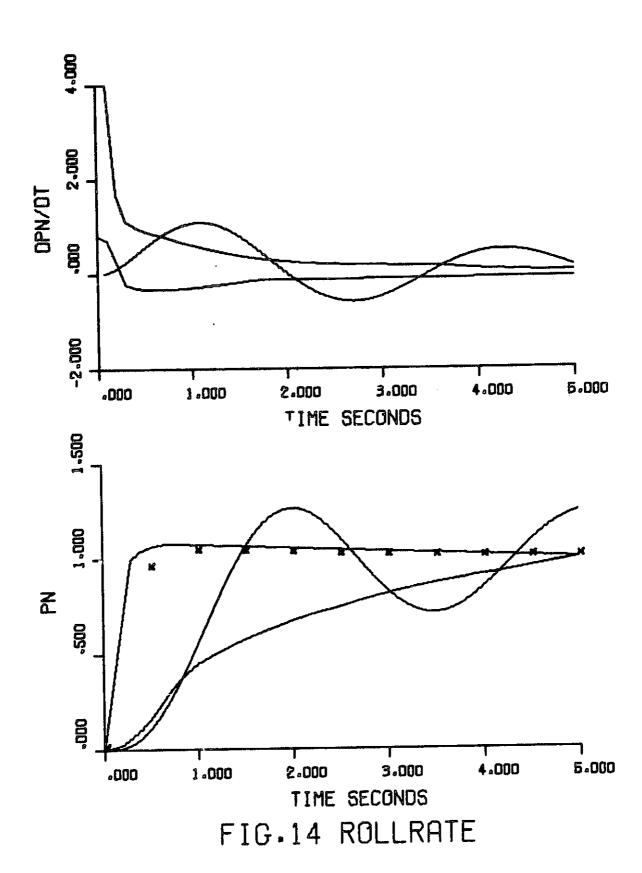
$$+ c_{2}\lambda_{2}\lambda_{3} + c_{3}\lambda_{2}\lambda_{3} + c_{2}\lambda_{2}\lambda_{4} + c_{4}\lambda_{2}\lambda_{4} + c_{1}\lambda_{1}\lambda_{2} + c_{2}\lambda_{1}\lambda_{2} = 0 \quad (33)$$

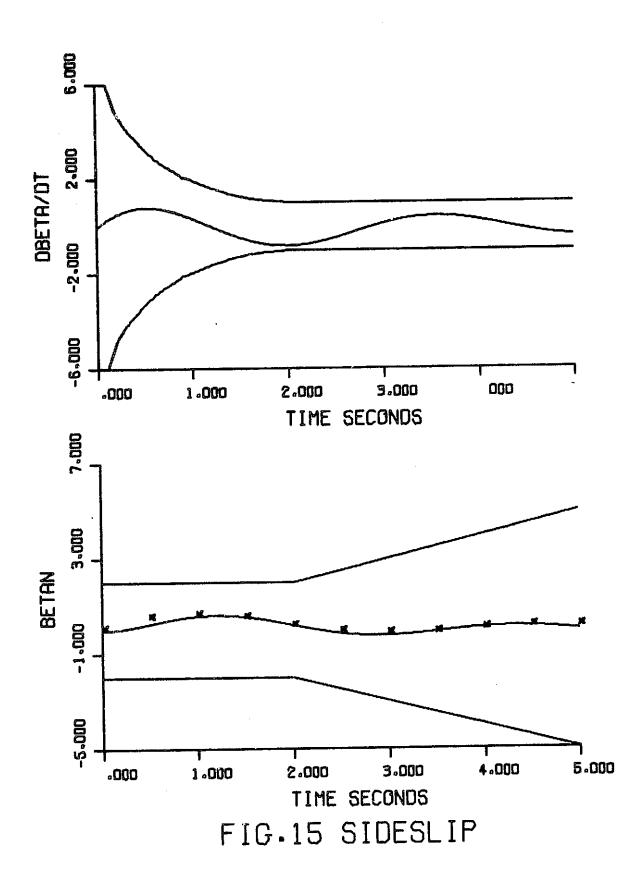
If three zeros are suppressed, only one parameter remains to be established by the minimization and the resulting representation of the input time history is inadequate.

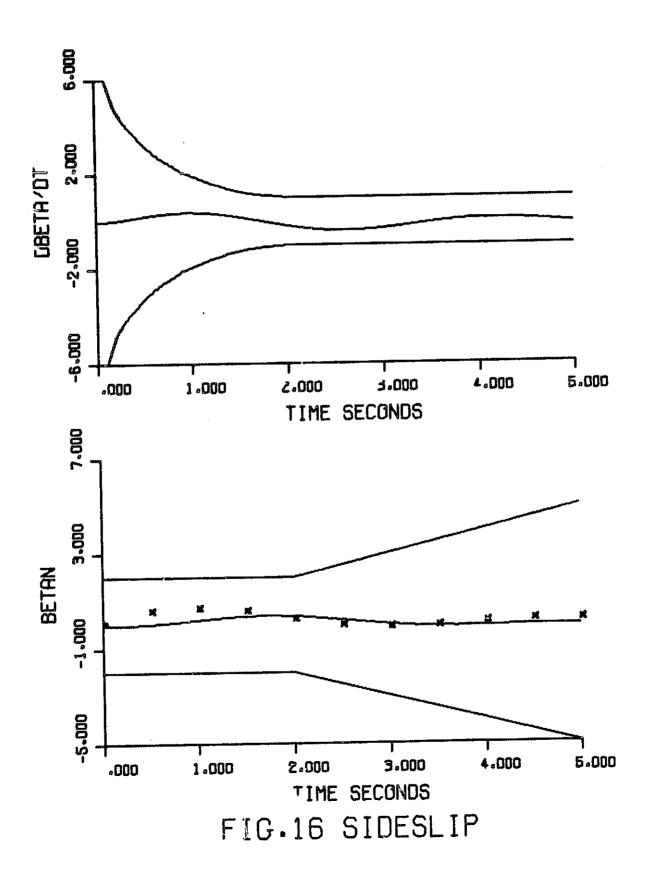
For low-order models, zero suppression has two detrimental effects on the models obtained. The first is the worsening of the agreement between the discretized input time histories and their analytical representations. For example, the unconstrained least-squared-error method yields a satisfactory fit of the roll-rate input, as shown in Figure 6. The continuous fitted curve has approximately the same relationship to the envelope as does the discretized input data. If the LSE method is constrained by equation 32 to have one less zero, one obtains the fit shown in Figure 13. If one further constrains the LSE minimization by equation 33, another zero will be eliminated and, for the example data, the fit is degraded to that shown in Figure 14. The same sequence is portrayed in Figures 7, 15, and 16 for the sideslip input. The Figure 7 results are unconstrained, one zero is suppressed in Figure 15 and two zeros are suppressed in Figure 16. Important features of the discrete inputs can be preserved by weighting the appropriate errors,  $\mathbf{e}_{\mathbf{z}}$ , in the LSE This may make the constrained fits more useful. Even the unconstrained cases can be altered. The risetime of the fitted roll rate can be reduced, for example. However, the overall fit cannot be improved by weighting.

The second detrimental effect of zero suppression is the increased tendency of the  $\underline{A}$  matrix to contain unrealistic values. The  $\underline{A}$  and  $\underline{b}$  arrays resulting from unconstrained fits of the input time histories are









and

The Newton-Euler procedure for obtaining the a<sub>ij</sub> converged in three iterations to a maximum variation of a<sub>ij</sub> ment from one iteration to the next of .00001 or less. This model was obtained from the unconstrained fits shown in Figures 6, 7, and 8.

If one zero in the roll-rate transfer function and one zero in the side-slip transfer function are suppressed, the  $\underline{A}$  and  $\underline{b}$  arrays are altered to

$$\underline{\mathbf{A}} = \begin{bmatrix} -3.49 & 4.73 & 97.14 & 0.52 \\ 0.96 & -3.42 & -22.48 & -.07 \\ -.19 & 0.30 & 4.00 & 0.02 \\ -.32 & 2.44 & 15.42 & 0.01 \end{bmatrix}$$

and

$$b = \begin{bmatrix} 0.00 \\ 1.06 \\ 0.00 \\ 0.87 \end{bmatrix}$$

The Newton-Euler procedure again required three iterations. This model was

obtained from the fits shown in Figures 13, 15, and 8.

If two zeros in the roll-rate transfer function and two zeros in the sideslip transfer function are suppressed, the  $\underline{A}$  and  $\underline{b}$  arrays are

$$\underline{A} = \begin{bmatrix} -9.34 & -1.66 & 403.88 & 2.75 \\ 3.51 & -2.88 & 138.62 & -.86 \\ -.21 & -.04 & 8.73 & 0.06 \\ -2.10 & 1.45 & 96.10 & 0.59 \end{bmatrix}$$

and

Three iterations were sufficient and the model was obtained from the data shown in Figures 14, 16, and 8.

The number of terms in the expansion of the state transition matrix specified by Paynter's recipe, equation 30, is a function of the largest absolute value contained in  $\underline{A}$  and this number is frequently larger than the practical limit of about 30 when zeros are suppressed.

The additional information required to calculate  $\underline{A}$  and  $\underline{b}$  from the discrete time histories shown in Figures 7-16 is given in Table 2. The specified eigenvalues were

$$\lambda_1 = -2.4$$

$$\lambda_2 = -.003$$

$$\lambda_{3,4} = -.25 + j2.0$$

AIRPLANE MODEL WITH SPECIFIED TIME HISTORIES

FLIGHT AND VEHICLE PARAMETERS

AIRSPEED 612.2 FT/SEC

CG TO PILCT STATICA LONGITUDINAL DISTANCE 22.24 FT

DIMENSIONAL CONSTANT FOR DSTAR EQUATION -. 3190 CUBIC-FEET/Le-SECONDS-SQUARED

DYNAMIC PRESSURE 331.8 LB/FT-SQUARED

ROLLRATE NORMALIZATION FACTOR . 500

SIDESLIP NORMALIZATION FACTOR 10.000

DSTAR NORMALIZATION FACTOR .010

Jetstar Parameters and Flight Conditions

Table 2

The eigenvalues and vehicle and flight parameters are approximately those of a Lockheed Jetstar, a four-engined utility transport [7], at 20,000 feet altitude and Mach = 0.6. It should be noted that the discrete input time histories were obtained from  $\mathbf{p}_n$ ,  $\mathbf{\beta}_n$ , and  $\mathbf{D}_n^\star$  responses sketched by an FRC engineer [8] and do not refer to a particular airplane or flight condition. Finally, FRC program CONTROL was used to calculate transfer function coefficients from the above A and b arrays in combination with the appropriate distribution matrices, calculated from equation 22, to verify the suppression of the specified zeros.

### VERIFICATION

Flight test data obtained from the FRC Lockheed Jetstar [9] provides a test case for the above model-generation procedure. For small, lateral variations about straight and level flight, the Jetstar can be represented by  $^{\star}$ 

$$\underline{A} = \begin{bmatrix} -2.353 & 0.735 & -11.050 & 0.000 \\ -.057 & 0.358 & 3.836 & 0.000 \\ 0.026 & -.999 & -.205 & 0.053 \\ 1.000 & 0.054 & 0.000 & 0.000 \end{bmatrix}$$

$$\underline{b} = \begin{bmatrix} 5.650 \\ 0.031 \\ -.001 \\ 0.000 \end{bmatrix}$$

<sup>\*</sup>Body axis nondimensional stability derivative parameters used in place of stability axis values for verification purposes only.

$$\widetilde{\mathbf{G}} = \begin{bmatrix} 1. & 0. & 0. & 0. \\ 0. & 0. & 1. & 0. \\ 0. & 0. & 0. & 1. \\ 14.75 & -7.044 & -146.0 & 32.14 \end{bmatrix}$$

$$\widetilde{\underline{\mathbf{n}}} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

The eigenvalues were

$$\lambda_1 = -.24045$$

$$\lambda_2 = -.00310$$

$$\lambda_{3,4} = -.25428 \pm j2.06475$$

CONTROL was used to calculate the handling-quality time histories for the period 0.0 to 5.0 seconds. The discrete input data extracted from the CONTROL output is given in Table 3. The flight and vehicle parameters are given in Table 2. The normalization factors were arbitrarily selected.

The responses of the resulting model are shown in Figures 17, 18, and 20 and compared with the discrete input values of Table 3 after normalization. The  $\underline{A}$ ,  $\underline{b}$ ,  $\underline{\widetilde{G}}$  and  $\underline{\widetilde{h}}$  arrays which define the model are

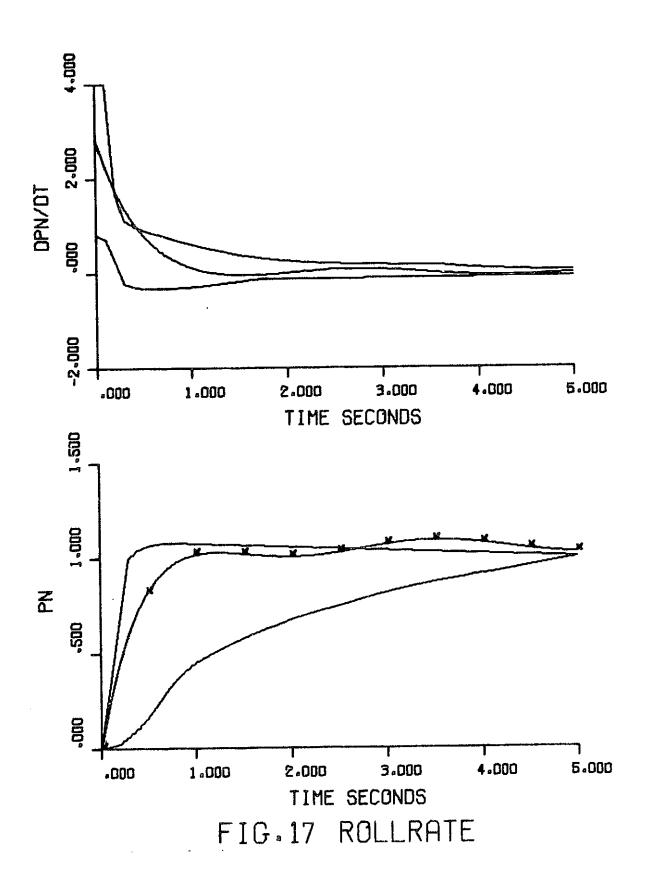
$$\underline{A} = \begin{bmatrix} -2.359 & 0.771 & -10.939 & -.003 \\ -.053 & -.359 & 3.849 & 0.000 \\ 0.025 & -1.005 & -.201 & 0.053 \\ 0.906 & -.021 & .278 & 0.003 \end{bmatrix}$$

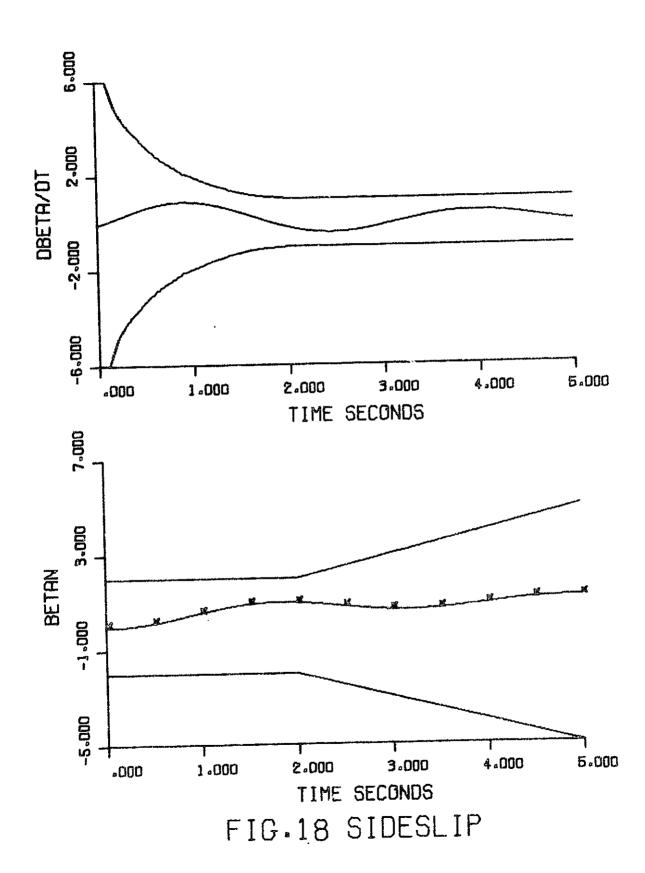
Table 3

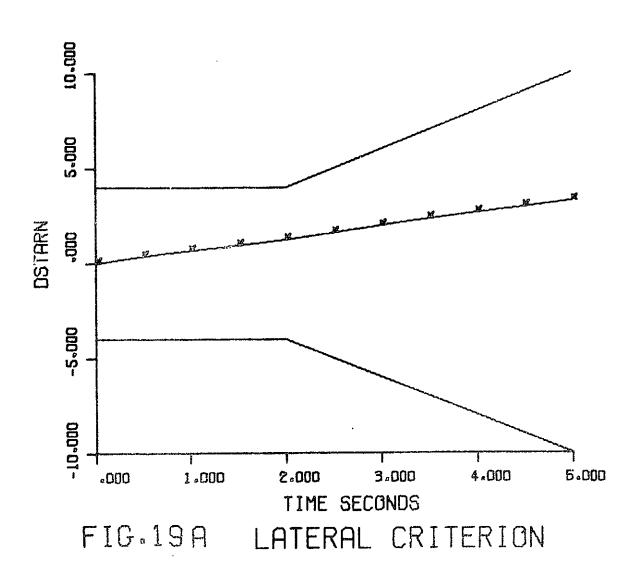
Time	Rollrate	Sideslip	D*
0.0	0.00	0.00	0.0
0.5	1.64	.016	37.6
1.0	2.04	.058	67.6
1.5	2.04	.093	95.1
2.0	2.01	.098	126.
2.5	2.06	.080	161.
3.0	2.14	.065	198.
3.5	2.18	.069	234.
4.0	2.15	.089	265.
4.5	2.09	.109	295.
5.0	2.05	.115	327.

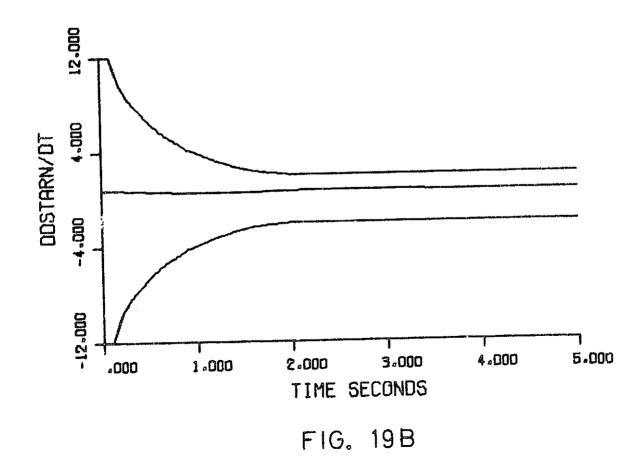
These values are multiplied by the normalization factors listed in Table 2 before they are plotted.

Jetstar Discrete Time-History Data









$$\widetilde{\mathbf{G}} = \begin{bmatrix} 1.0 & 0. & 0. & 0. \\ 0. & 0. & 1. & 0. \\ 0. & 0. & 0. & 1. \\ 14.35 & -11.13 & -143.5 & 32.61 \end{bmatrix}$$

$$\tilde{h} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -0 & 0 & 0 & 0 \end{bmatrix}$$

These results are close to the original arrays. The differences are attributed to the truncation of the CONTROL output values to two or three significant figures to approximate imprecise or sketched input data.

#### DISCUSSION

The problem of obtaining an  $\underline{A}$  and  $\underline{b}$  from specified output time histories is one of nonlinear, noisefree identification. Five techniques for solving this problem have been suggested. The minimization of a cost functional which measures the differences between a trial solution and the handling-quality time-history envelopes would consume a large amount of computer time and there is no assurance that such a cost functional would be sufficiently well behaved to have a useful solution. Similarly, one could consume a large amount of computer time seeking solutions by random direct search. A graduate student is currently working on a variation of direct search in which the sensitivity of the time-history errors to changes in the  $\underline{A}$  matrix elements is calculated. Then a set of incremental changes to the  $\underline{A}$  elements can be obtained.

The Laplace transformation method is also being pursued by a graduate student. In this form the problem is quite easily formulated but is ill-posed. It remains to be seen whether this method can advantageously incorporate the loose bounds on the eigenvalues or not. It also has the disadvantage of being a two-approximate-step process. One obtains  $\underline{y}(t)$  from  $\hat{\underline{y}}(t)$  and then  $\underline{\tilde{y}}(t)$  from  $\underline{y}(t)$  except that the latter two will not coincide as they do in the pseudodata method. The Laplace transformation method and the sensitivity matrix method do have the advantage that they can be made to yield  $\underline{A}$  matrices of the form of equation 19.

The remaining approach, the pseudodata method has two advantages. It contains only one approximation step and it is numerically efficient. The disadvantages are that it is somewhat less general and yields unconstrained  $\underline{A}$  matrices. Experience has shown that the transfer functions resulting from

the unconstrained  $\underline{A}$  matrices resemble those produced by  $\underline{A}$  matrices of the form of equation 19. The pseudodata method results in a well-posed set of bilinear algebraic equations which yield an  $\underline{A}$  matrix having the specified eigenvalues.

The pseudodata method is the only method which readily achieves zero suppression. In the other methods zero suppression contributes to their ill-posedness making useful solutions even more numerically difficult to obtain. The utility of any zero-suppressed solution is called into doubt by the detrimental effect suppression has on the LSE fit of the discretized input data (see Figures 13, 14, 15, and 16). Relieved of the need to suppress transfer-function zeros, one might prefer one of the other methods.

APPENDIX A
Use of Program AANDB

#### INTENDED OPERATION

- 1. Put in normalized discrete data
- 2. Obtain normalized responses
- 3. Put in normalization factors
- 4. Obtain the normalizing distribution matrix
- Obtain the non-normalized airplane equations in state-space form.
- 6. Use CONTROL to obtain transfer functions

Steps 1 through 5 are performed by an example Fortran program AANDB for the fourth-order small-lateral-motion case. The structure of the program is shown in Figure A-1. The subroutines perform the following tasks:

MUGEN: Calculates eigenvalues from input time-history data.

CASE1\* (with entry points CASE2 and CASE3): Calculates the  $c_1$  required to fit  $c_1e^{\lambda_1t}+c_2e^{\lambda_2t}+c_3e^{\lambda_3t}+c_4e^{\lambda_4t}+c_5$  to the input time-history data.

LISTER: Prints information from COMMON on demand.

FITTING: Fits a polynomial to roll-rate data and integrates it to produce roll-angle pseudodata.

MODEL: Calculates the plant matrix,  $\underline{A}$ , input distribution vector,  $\underline{b}$ , the output distribution matrix,  $\underline{G}$ , and the input/output coupling vector,  $\underline{h}$ .

RESPONS: Integrates the plant equations to produce comparison time histories.

 $<sup>^*</sup>$ CASE1 does not suppress any transfer function zeros, CASE2 suppresses one zero and CASE 3 suppresses two zeros.

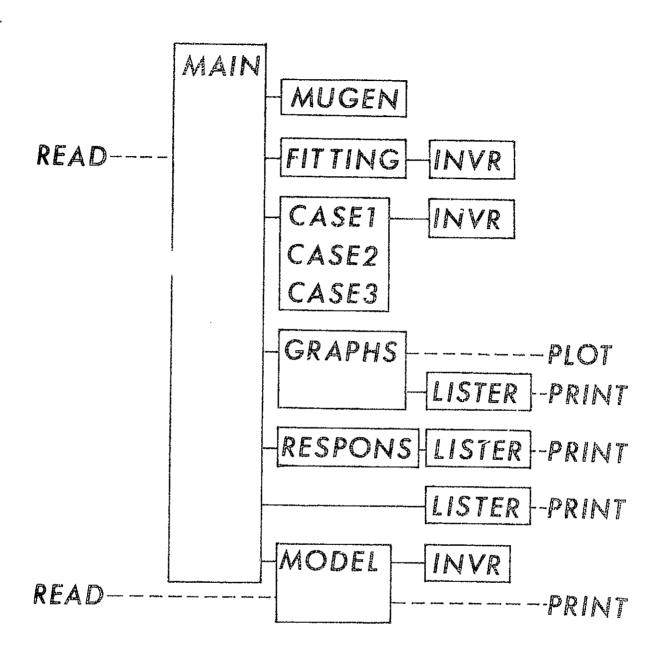


FIG. A1

CRAPHS: Plots envelopes and time histories and their first derivatives.

INVR: Inverts matrices.

The first fourteen input data cards are read by MAIN. The final two input data cards are read by subroutine MODEL. The input data cards contain the following information:

# 1st data card: NN(20); 2012

- - NN(2) = 1: LISTER will print eigenvalues obtained from input time histories
  - NN(3) = 1: LISTER will print eigenvalues specified by user
  - NN(4) = 1: LISTER will print roll angle data obtained from roll rate
  - NN(5) = 1: LISTER will print complex coefficient matrix C
  - NN(6) = 1: LISTER will print summary of time-history curve fitting results
  - NN(7) = 1: not used
  - NN(8) = 1: not used
  - NN(9) = 1: LISTER will print envelopes for PN, BETAN, DSTAR & derivatives
  - NN(10) = 1: LISTER will print fitted curves for PN, BETAN, DSTAR & derivatives
  - NN(11) = 1: LISTER will print number of terms included in series for  $e^{\Delta \Delta t}$
  - NN(12) = 1: LISTER will print difference equation  $\underline{P}$  matrix
  - NN(13) = 1: LISTER will print difference equation g vector
  - NN(14) = 1: LISTER will print responses obtained by integrating model equations
  - NN(15) = 1: LISTER will print derivatives of responses obtained from P, q

NN(16) = 1: LISTER will print "PN PLOTTED" if NPLOT requests it

NN(17) = 1: LISTER will print "BETAN PLOTTED" if NPLOT requests it

NN(18) = 1: LISTER will print "DSTAR PLOTTED" if NPLOT requests it

NN(19) = 1: not used

NN(20) = 1: not used

2nd - 12th data cards: TIME, PN, BETAN, DSTAR; 4F10.0

0.0	0.0	0.0	0.0
0.5	PN(.5)	BETAN(.5)	DSTAR(.5)
1.0	PN(1.)	BETAN(1.)	DSTAR(1.)
1.5	PN(1.5)	BETAN(1.5)	DSTAR(1.5)
2.0	PN(2.)	BETAN(2.)	DSTAR(2.)
2.5	PN(2.5)	BETAN(2.5)	DSTAR(2.5)
3.0	PN(3.)	BETAN(3.)	DSTAR(3.)
3.5	PN(3.5)	BETAN(3.5)	DSTAR(3.5)
4.0	PN(4.)	BETAN(4.)	DSTAR(4.)
4.5	PN(4.5)	BETAN(4.5)	DSTAR(4.5)
5.0	PN(5.)	BETAN(5.)	DSTAR(5.)

13th data card: MCASE, NPLOT, NHIST; 314

If NHIST  $\neq$  0 subroutine RESPONS will be called to calculate the model time histories. If NPLOT  $\neq$  0 subroutine graphs will be called to plot the model time histories according to:

#### **NPLOT**

- no plots
- PN and PNDOT plotted
- BETAN and BETANDOT plotted
- PN, PNDOT, BETAN, BETANDOT plotted
- PSTAR, DSTARDOT plotted BETAN, BETANDOT, DSTAR, DSTARDOT plotted 5
- PN, PNDOT, DSTAR, DSTARDOT plotted
- 7 all plots
- no plots

### MCASE must be appropriate for:

- GO TO(1,2,3,4,5,6,7,8,9), MCASE
- P(s) has no zero(s) suppressed  $\beta(s)$  has no zero(s) suppressed 1
- P(s) has two zero(s) suppressed  $\beta(s)$  has one zero(s) suppressed
- P(s) has one zero(s) suppressed
- β(s) has two zero(s) suppressed
- P(s) has one zero(s) suppressed B(s) has one zero(s) suppressed
- P(s) has one zero(s) suppressed 5 β(s) has no zero(s) suppressed
- P(s) has no zero(s) suppressed  $\beta(s)$  has one zero(s) suppressed 6
- 7 P(s) has two zero(s) suppressed B(s) has no zero(s) suppressed
- 8 P(s) has no zero(s) suppressed  $\beta(s)$  has two zero(s) suppressed
- 9 P(s) has two zero(s) suppressed  $\beta(s)$  has two zero(s) suppressed

## 14th data card: specified eigenvalues; 8F10.0

1-10 First eigenvalues which is real

21-30 Second eigenvalue which is also real

41-50 Real part of third eigenvalue

51-60 Imaginary part of third eigenvalue

61-70 Real part of fourth eigenvalue

71-80 Imaginary part of fourth eigenvalue

15th card: velocity, length,  $c_3$ ,  $q_{co}$ ,  $P_{ss}$ ,  $\beta_{ss}$ ,  $D_{ss}^*$ ; 7F10.0

VELOCITY: Nominal airspeed in ft/sec

LENGTH: Centerline length from CG to pilot in ft

 $c_3$ : Dimensional constant for  $D^*$ 

q<sub>co</sub>: Nominal dynamic pressure in 1b/ft<sup>2</sup>

p<sub>ss</sub>: Roll rate normalization factor

 $\beta_{ss}$ : Sideslip normalization factor

 $D_{\varsigma\varsigma}^{\star}$ : DSTAR normalization factor

16th data card: Newton-Euler parameters; 14, F20.0

ITMAX, 14, Maximum number of iterations of Newton-Euler algorithm

EPSI, F20.0, when every unknown (the elements of the A matrix) changes by an amount smaller than EP:I, the Newton-Euler Algorithm stops

Note: 50,0.00001 seem to work well.

#### INTERPRETATION OF THE PRINTED OUTPUT

If NN = 20\*1 all of the following output will be produced:

LISTER calls from the main program print:

- 1. Date, list table NN, case number, plot request code, time response code and the input time history data.
- 2. Real and imaginary parts of each MU(4) and EI(4) obtained from the input time histories. The EI are eigenvalues,  $\lambda_i$ , and each MU is  $\mu_i = e^{0.5\lambda}i$  where 0.5 is the uniform time interval between input time-history data points.
- 3. Real and imaginary parts of the specified eigenvalues and associated MU values. These are the eigenvalues used in the least-square fitting process to obtain <u>C</u>, not the quantities derived from the data. The derived values are presented only for comparison purposes.
- 4. The PHI or roll-rate psudodata generated from the PN or roll rate input time history. The time intervals are the same as for the original data.
- 5. The TIME RESPONSE COEFFICIENTS matrix,  $\underline{C}^{\,\prime}$ , is printed. This is a 4 x 5 array of complex numbers:

$$y = \underline{C}e^{\Lambda t} + \underline{C}$$
, where  $\underline{C}' = [\underline{C}:\underline{C}]$ ,

which analytically represents the input time histories. This y(t) is printed as: FITTED TIME RESPONSES by a call to LISTER from RESPONS.

6. A summary printout of MU, EI, C and c

LISTER calls from subroutine RESPONS print:

1. The envelopes, upper and lower boundaries, for  $p_n$   $\beta_n$ ,  $D^*$ ,  $\frac{d}{dt}$   $p_n$ ,  $\frac{d}{dt}$   $\beta_n$ , and  $\frac{d}{dt}$   $D^*$ . Values are given for every 0.1 seconds. These values are stored

in DATA statements in the main program.

- 2. The curves which have been fitted to the input time-history data are printed for  $p_n$ ,  $\beta_n$  and  $D^*$ . The analytic expressions for the curves are differentiated and tabulated also giving  $\frac{d}{dt} p_n$ ,  $\frac{d}{dt} \beta_n$  and  $\frac{d}{dt} D^*$ .
- 3. The number of terms taken to calculate the truncated series used to represent  $e^{A\Delta t}$  is PAYNTERS RECIPE NUMBER. See CONTROL, Takahashi, et. al., page 103 [6].
  - 4. The difference equation parameters  $\underline{P}$  and  $\underline{q}$  in:

$$\bar{x}_{k+1} = 5\bar{x}_k + 5u_k$$
,  $\bar{x}_0 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ 

- 5. The numerically integrated response time histories  $\underline{y}_k$  where  $\underline{y}_k = \underline{G}\underline{x}_k + \underline{h}u_k$
- 6. The first derivatives of the integrated responses are tabulated at 0.1 second intervals. They are obtained from

$$\dot{x}_k = Ax_k + bu_k$$

and

$$\dot{\underline{y}}_{k} = \underline{G}\dot{\underline{x}}_{k}$$

LISTER calls from subroutine GRAPHS prints:

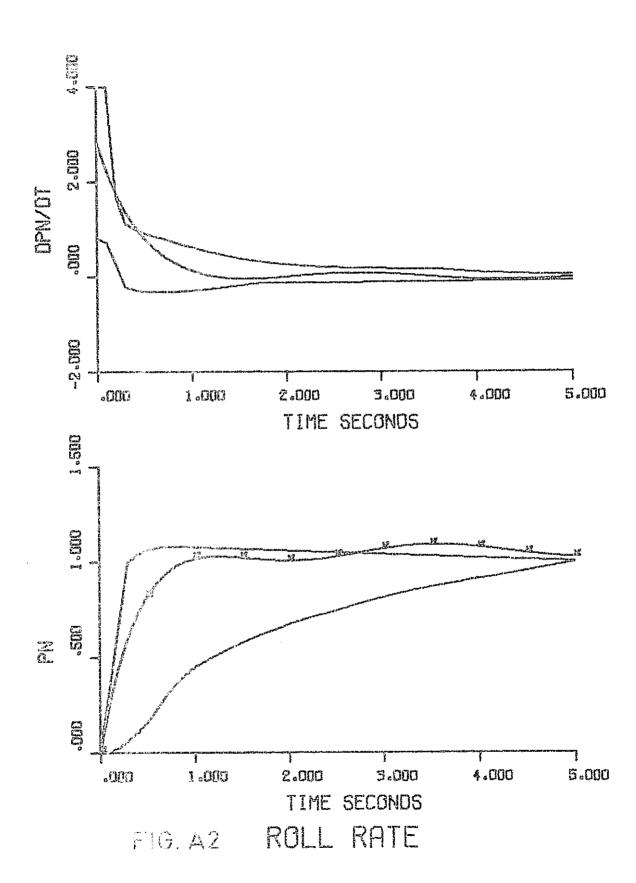
If MPLOT is such that plots are requested, LISTER will print "PN

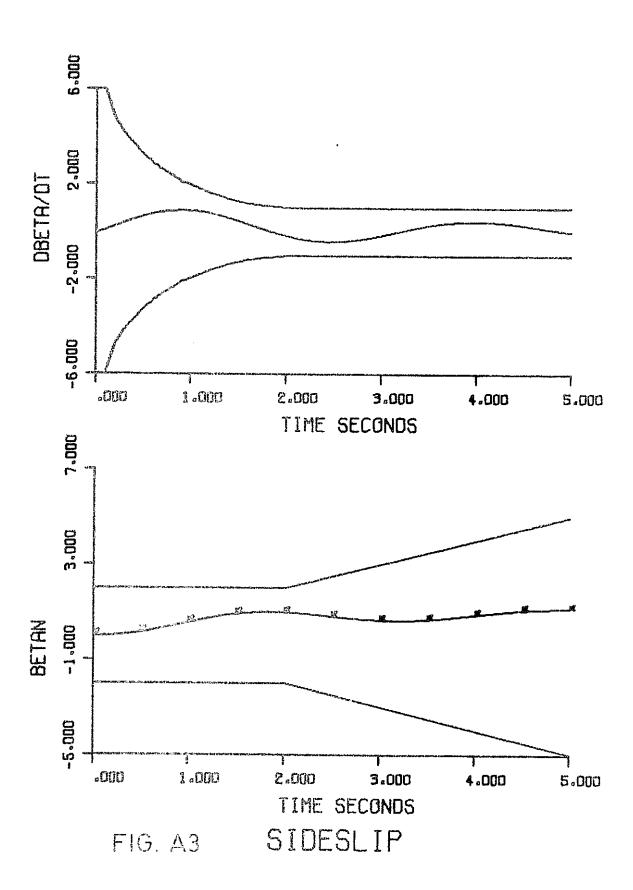
PLOTTED" if  $\rho_n$  and  $\frac{d}{dt}$   $\rho_n$  plots have been generated, "BETAN PLOTTED" if  $\beta_n$  and  $\frac{d}{dt}$   $\beta_n$  plots have been generated and "DSTAR PLOTTED" if D\* and  $\frac{d}{dt}$  D\* plots have been generated. The envelopes are automatically added to each plot.

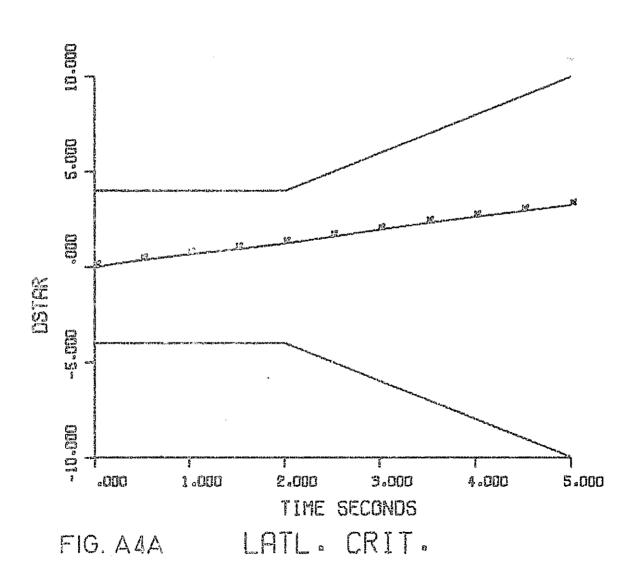
#### SAMPLE PLOTTED OUTPUT

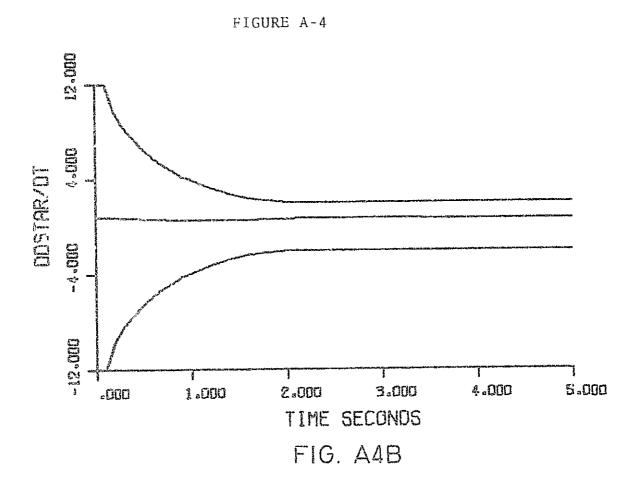
Plots are produced in three groups which can be requested individually or in any combination. These groups, the PN group, the BETAN group and the DSTAR group, consist of a title line, a lower graph and an upper graph. Each lower graph shows the upper envelope boundary, the lower envelope boundary, the analytical curve which has been fitted to the input data and the time history obtained by integrating the equations of motion. These four traces are represented by continuous lines and are plotted versus time on the horizontal scale. The fitted and integrated lines should coincide. In addition, the lower graph contains eleven discrete symbols representing the input data.

Each upper graph shows the upper envelope boundary, the lower envelope boundary, the first derivative of the fitted analytical curve and the first derivative of the integrated time response. The last two should coincide. All four curves are represented by continuous lines and are plotted versus time on the horizontal scale. A PN group sample is shown in Figure A-2, a BETAN group sample is shown in Figure A-3 and a DSTAR group is shown in Figure A-4. The example plots are unusual in that the original data was generated by a linear simulation program using a fourth-order model. Thus one should expect excellent agreement between the input data and the fitted and integrated results. Data obtained from other sources will not be matched as well.









## EXPERIENCE WITH THE PROGRAM

Several bounds on program flexibility exist. The first involves the generation of eigenvalues from input-time history data. Subroutine MUGEN does calculate a set of  $\boldsymbol{\lambda}_i$  from each set of eleven points representing one input time history. These values are not correct or consistent even when the data is carefully contrived for best results. This is due to the dependence of the  $\lambda_{i}$  calculation upon differences between adjacent (in time) data values. In anticipation of the program being normally used with data obtained graphically, the values used in the example were held to three significant figures. This so degraded the  $\lambda_{\hat{i}}$  calculation that the values from the three input time hisories varied from the known values used to generate the data by two orders of magnitude in the case of small eigenvalues and occasionally had the opposite In general, the complex eigenvalues were more closely identified than the real eigenvalues. This was particularly true if the data precision was increased. In view of the anticipated character of the input data and the desirability of specifying the eigenvalues of the resulting model, no further development of MUGEN is planned.

A second difficulty arises when zero suppression is specified. Subroutine CASE2 and CASE3 calculate coefficients, C, which yield transfer functions having the correct pole-zero excesses. The resulting expression will normally be a poor representation of the input time-history data but that is unavoidable. Unfortunately, the suppression of zeros also tends to ill-condition the numerical equations which must be solved to obtain A. In extreme cases this prevents convergence of the simple Newton-Euler-Raphson algorithm employed in MODEL.

Finally, there is a general difficulty that may interfere with the integration of the model equations of motion in RESPONS. If the A matrix is ill-conditioned an unworkable number of terms in the series approximation for  $e^{A\Delta t}$  may be required. This is caused by the fixed  $\Delta t$  of 0.1 seconds which is built into RESPONS. A limit of 30 terms is imposed. Other limitations will undoubtedly come to light as experience with the program accumulates.

APPENDIX B
Program AANDB Listing

```
MAI
                                                                               10
 PROGRAM AANDB (INPUT, OUTPUT)
 COMMON / NAMES/NN(20), PN(11), BETAN(11), DSTAR(11), TPN(11)
                                                                        MAT
                                                                               20
             .PNF(51), BETANF(51), DSTARF(51), PN1F(51), BETAN1F(51), DSTMAI
                                                                               30
2AR1F(51), PNC(51), BETANC(51), DSTARC(51), PN1C(51), BETAN1C(51), DSTAR1MAI
                                                                               40
30(51), APN(11), ABETAN(11), ADSTAR(11), BPN(11), BBETAN(11), BOSTAR(11), MAI
                                                                               50
                                                                               60
                                                                        MAI
4PHIN(11)
                                                                               70
                                   C. NCASE, MCASE, NZ,
                                                                 NPLOT, MAI
 COMMON /PARAM/MU, EIGEN,
1 NHIST, PNFINAL, BNFINAL, OSFINAL, TIME (51), P (4,4), Q (4)
                                                                        MII
                                                                               80
 CCMMON /LIMITS/PNU(51) .PNL (51) .BETANU(51) .BETANL(51) .DST ARU(51) .
                                                                        MAI
                                                                               90
1DSTARL(51), PN1U(51), PN1L(51), BETAN1U(51), BETAN1L(51), DSTAR1U(51),
                                                                        MAT
                                                                              100
                                                                              110
                                                                        MIIM
2DSTAR1L(51)
 COMMON /FINAL/ PSS, RETASS, DSTARSS, DP, DR. DBETA, DPHI, A(4,4), B(4), DDEMAI
                                                                              120
                                                                              130
1 L TA
                                                                        MAI
                                                                              140
 COMPLEX MU(4) , EIGEN(4) , C(5,4)
 DATA PNU/.D, .333..667, 1.0, 1.043, 1.064, 1.076, 1.08, 1.08, 1.078, 1.076, MAI
                                                                              150
11.074, 1.072, 1.07, 1.069, 1.067, 1.065, 1.063, 1.061, 1.059, 1.057, 1.055, 1MAI
                                                                              160
2.053,1.051,1.05,1.048,1.045,1.044,1.042,1.04,1.038,1.036,1.034,1.0MAI
                                                                              170
332,1.03,1.029,1.027,1.025,1.023,1.021,1.019,1.017,1.015,1.013,1.01MAI
                                                                              180
41.1.01,1.008,1.006,1.004,1.002,1.0/,PNL/0.0,0.01,0.027,0.065,0.107MAI
                                                                              196
5.0.16.0.227.0.3.0.36.0.409.0.45.0.479.0.507..53.0.556..579.0.6.0.6MAI
                                                                              200
62,0.639,0.656,0.677,0.692,0.708,0.722,0.733,0.748,0.762,0.778,0.79M%I
                                                                              210
7,0.804,0.816,0.829,0.84,0.852,0.861,0.871,0.88,0.888,0.896,0.908,0MAI
                                                                              220
8.915,0.92,0.929,0.938.0.947.0.956.0.965.0.974.0.983.0.992.1.0/
                                                                              230
 DATA BETANU/21*2.0,2.1,2.2,2.3,2.4,2.5,2.6,2.7,2.8,2.9,3.0,3.1,3.2MLI
                                                                              240
1,3.3,3.4,3.5,3.6,3.7,3.8,3.9,4.0,4.1,4.2,4.3,4.4,4.5,4.6,4.7,4.8,4MAI
                                                                              250
2.9,5.3/, BETANL/21*-2.0,-2.1,-2.2,-2.3,-2.4,-2.5,-2.6,-2.7,-2.8,-2.MAI
                                                                              260
39,-3.0,-3.1,-3.2,-3.3,-3.4,-3.5,-3.5,-3.7,-3.8,-3.9,-4.8,-4.1,-4.2MAI
                                                                              270
                                                                              280
4,-4,3,-4,4,-4,5,-4,6,-4,7,-4,8,-4,9,-5,0/
                                                                        MAI
                                                                              290
 DATA DSTARU/21 *4.0, 4.2, 4.4, 4.5, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0, 6.2, 6.444I
1,6.6,6.8,7.0,7.2,7.4,7.6,7.8,8.0,8.2,8.4,8.6,8.8,9.0,9.2,9.4,9.5,9MI
                                                                              300
        10.0/.DSTARL/21#-4.0,-4.2,-4.4,-4.6,-4.8,-5.0,-5.2,-5.4,-5.MAI
                                                                              310
36 ,-5.8,-6.0,-6.2,-6.4,-6.5,-6.8,-7.0,-7.2,-7.4,-7.6,-7.8,-8.0,-8.MAI
                                                                              320
                                                                              330
4 2,-8.4,-8.6,-8.8,-9.0,-9.2,-9.4,-9.6,-9.8,-10.0/
                                                                        MAI
 DATA PN1 U/4.0, 4.0, 1.686, 1.122, 0.932, 0.908, 0.843, 0.797, 0.724, 0.663, MAI
                                                                              340
10.613,0.556,0.510,0.464,0.421,0.379,0.349,0.318,0.295,0.272,0.257,MAI
                                                                              350
20.234,0.222,0.211,0.199,0.192,0.188,0.184,0.180,0.175,0.172,0.168,MAI
                                                                              350
30.165, 0.169, 0.165, 0.165, 0.157, 0.142, 0.119, 0.107, 0.096, 0.080, 0.073, MAI
                                                                              370
40.059.0.061.0.054.0.046.0.046.0.046.0.046.0.046/0.046/.PN1L/0.306.0.711, M& I
                                                                              380
```

```
50.255,-.224,-.297,-.323,-.327,-.323,-.319,-.304,-.289,-.274,-.251,MAI
                                                                              390
 6-.228,-.205,-.183,-.148,-.129,-.125,-.118,-.125,-.123,-.121,-.120,MAI
                                                                              400
 7-.113,-.116,-.114,-.112,-.110,-.109,-.107,-.105,-.103,-.102,-.100,MAI
                                                                              410
 8-.098,-.096,-.095,-.093,-.091,-.089,-.088,-.086,-.084,-.082,-.081,MAI
                                                                              420
                                                                              430
 9-.079,-.077,-.075,-.074,-.072/
  DATA BETAN1U/6.0.6.0.4.80,4.15,3.72,3.28,2.91,2.61,2.37,2.10,1.95,MAI
                                                                              440
 11.78,1.61,1.49,1.35,1.26,1.17,1.12,1.07,1.05,1.00,30*1./.RETANIL/ MAI
                                                                              450
 2-6.0,-6.0,-4.80,-4.15,-3.72,-3.28,-2.91,-2.61,-2.37,-2.10,-4.95,
                                                                              460
 3-1.78,+1.61,-1.49,-1.35,-1.26,-1.17,-1.12,-1.07,-1.05,-1.00,30*-1.MAI
                                                                              470
                                                                              480
                                                                         49 T
 40/
  DATA DSTAR1U/12.0,12.0,9.65,8.30,7.44,6.56,5.82,5.22,4.74,4.20,
                                                                         MA T
                                                                              490
 13.90,3.55,3.22,2.98,2.70,2.52,2.34,2.24,2.14,2.10,2.00,30*2.0/,
                                                                         MAI
                                                                              500
 2DSTAR1L/-12.0,-12.0,-9.60,-8.30,-7.44,-6.56 ,-5.82,-5.22,-4.74,
                                                                              510
                                                                         TAP
 3-4.20, -3.90, -3.56, -3.22, -2.98, -2.70, -2.52, -2.34, -2.24, -2.14, -2.18, MXI
                                                                              520
                                                                              530
                                                                         MAI
 4-2.00.30*-2.0/
                                                                         MAT
                                                                              540
  READ 300,NN
                                                                              556
                                                                         MAT
  READ 100, (TPN(I), PN(I), BETAN(I), OSTAR(I), I=1, 11)
                                                                              560
                                                                         MAI
  READ 200, MCASE, NPLOT, NHIST
                                                                              570
                                                                         TAP
  IF(NN(1).EQ.1) CALL LISTER(1)
                                                                              580
                                                                         MAI
  CALL MUGEN (PN: MU, EIGEN)
                                                                              590
                                                                         MA I
  IF(NN(2).EQ.1) CALL LISTER(2)
                                                                         MAI
                                                                              600
  CALL MUGEN(BETAN, MU, EIGEN)
                                                                         MA T
                                                                              610
  IF(NN(2).EQ.1) GALL LISTEP(2)
                                                                         MAI
                                                                              620
  CALL MUGEN(DSTAR, MU, EIGEN)
                                                                         MAI
                                                                               530
  IF(NN(2).EQ.1) CALL LISTER(2)
                                                                               540
                                                                         MAT
   READ 400 - EIGEN
                                                                               650
                                                                         MAI
  MU(1)=CE XP(E IGEN(1) *.5)
                                                                         MIT
                                                                               560
  MU(2) = CEXP (EIGEN (2) *.5)
                                                                               670
                                                                         MAI
   MU(3) = CEXP(EIGEN(3) + .5)
                                                                               580
                                                                         MAI
   MU(4) = CONJG(MU(3))
                                                                              590
                                                                         MAI
   IF(NN(3).EQ.1) CALL LISTER(3)
                                                                               700
                                                                         MAI
   CALL FITTING (PN, TPN, APN)
                                                                         MAI
                                                                               710
   DO 10 I=1,11
                                                                         MAI
                                                                              720
   PHIN(I)=0.
                                                                         MAI
                                                                               730
   pp 10 J=1.11
                                                                         MAI
                                                                               740
10 PHIN(I)=PHIN(I)+APN(J)* TPN(I)**(12-J)/FLOAT(12-J)
                                                                         MAI
                                                                               750
   IF(NN( 4).EQ.1) CALL LISTER(4)
                                                                         MAI
                                                                               760
   GO TO (1,2,3,4,5,6,7,8,9), MCASE
                                                                         MAI
                                                                               770
 1 CALL CASE1(MU, PN, EIGEN, C(1,1))
                                                                               780
                                                                         MET
   CALL CASE1(MU, PETAN, EIGEN, C(1,2))
```

GO TO 11	
2 CALL CASE3(MU, PN. EIGEN, C(1.1))	
CALL CASE2 (MU, BETAN, EIGEN, C(1, 2)	•
CALL CASE1(MU, PHIN, EIGEN, C(1, 3))	
CALL CASE1 (MU, DSTAR, EIGEN, C(1,4)	)
IF(NN(5).EQ.1) CALL LISTER(5)	
GO TO 11	
3 CALL CASE2(MU.PN.EIGEN. C(1.1))	
CALL CASE3 (MU, BETAN, EIGEN, C(1, 2)	
CALL CASE1(MU, PHIN, EIGEN, C(1,3))	
CALL CASE1 (MU, ESTAR, EIGEN, C(1, 4)	)
<pre>IF(NN(5).EQ.1) CALL LISTER(5)</pre>	
GO TO 11	
4 CALL CASE2(MU, PN, EIGEN, C(1,1))	
CALL CASE2(MU, BETAN, EIGEN, C(1,2)	)
CALL CASE1(MU, PHIN, EIGEN, C(1,3))	
CALL CASE1 (MU, DSTAR, EIGEN, C(1,4)	•
IF(NN(5).EQ.1) CALL LISTER(5)	
GO TO 11	
5 CALL CASE2(MU, PN, EIGEN, C(1.1))	
CALL CASE1(MU, BETAN, EIGEN, C(1,2)	1
CALL CASE1 (MU, PHIN, EIGEN, C(1,3))	
CALL CASE1(MU.DSTAR, EIGEN, C(1,4)	•
IF(NN(5).EQ.1) CALL LISTER(5)	
GO TO 11	
6 CALL CASE1(MU, PN, EIGEN, C(1, 1))	
CALL CASE2(MU, BETAN, EIGEN, C(1,2)	
CALL CASE1 (MU.PHIN, EIGEN. C(1,3))	
CALL CASE1 (MU, DSTAR, EIGEN, C(1,4)	)
IF(NN(5).EQ.1) CALL LISTER(5)	
GO TO 11	
7 CALL CASE3(MU, PN, EIGEN, C(1.1))	
CALL CASE1 (MU, BET AN . EIGEN, C(1,2)	
CALL CASE1 (MU. PHIN. EIGEN. C(1.3))	
CALL CASE1(MU.DSTAR, EIGEN. C(1.4)	)
IF(NN(5).EQ.1) CALL LISTER(5)	
60 70 11	

CALL CASE1(MU, PHIN, EIGEN, C(1,3))

IF(NN(5).EQ. 1) CALL LISTER(5)

CALL CASE1 (MU, DSTAR, EIGEN, C(1,4))

M% I 790 MAI 800 HAI 810 I SM 820 MAI 830 840 MA I MAI 850 MAI 860 MAI 870 MAI 880 I &M 890 MAI 900 MAI 910 920 MAI 930 MAI MAI 940 MAI 950 MAI 960 970 MAI MAI 980 MRI 990 MAT 1000 MAI 1010 M&I 1020 MAI 1030 MAI 1040 MAI 1058 MAI 1060 MAI 1070 **441 1880** MAI 1098 MAI 1100 MAI 1110 M&I 1120 MAI 1130 MAI 1140 MAI 1150 MI 1160 MAI 1170 MAI 1180

```
MAI 1190
  8 CALL CASE1(MU, PN, EIGEN, C(1.1))
                                                                          MAI 1200
    CALL CASES(MU. BETAN, EIGEN. C(1.21)
                                                                          MAI 1210
    CALL CASE1(MU, PHIN, EIGEN, C(1, 3))
                                                                          MAI 1220
    CALL CASE1(MU. DSTAR, EIGEN, C(1.4))
                                                                          MAI 1230
 9 CALL CASES(MU,PN,EIGEN, C(1,1))
                                                                          MAI 1240
    CALL CASES (MU, BETAN, EIGEN, C(1, 2))
                                                                          MAI 1250
    CALL CASE1(MU, PHIN, EIGEN, C(1,3))
                                                                          WAI 1260
    CALL CASE1 (MU. DSTAR, EIGEN. C(1.4))
                                                                          MAI 1270
    IF(NN(5) .EQ. 1) CALL LISTER(5)
                                                                          MAI 1280
 11 IF(NN(6) .EQ.1) CALL LISTER(6)
    CALL MCDEL(C, EIGEN, PSS, BETASS, DSTARSS, DP, DR, OBETA, DPHI, A, B, ODELTA) MAI 1290
                                                                          MAI 1300
    IF(NHIST.NE.O) CALL RESPONS
                                                                          MAI 1310
    IF(NPLOT.NE.D) CALL GRAPHS
                                                                          MAI 1320
    STOP
                                                                          MAI 1330
100 FORMAT(4F10.0)
                                                                          MAI 1340
200 FORMAT (3 14)
                                                                          MAI 1350
380 FORMAT (2012)
                                                                          MAI 1360
400 FORMAT(8F10.0)
                                                                          MAI 1370
    END
```

	The state of the s	MUG	10
	SUBROUTINE MUGEN(D,MU,EIGEN) DIMENSION D(11) ,P(4,4),Q(4),PI(4,4),A(4)	MUG	20
		MUG	30
	COMPLEX MU(4), EIGEN(4), SAVE	MUG	40
	P(1,4)=D(2)-D(1)	MUG	50
	P(1,3)=D(3)-D(2)	MUG	60
	P(1,2) = P(2,4) = D(4) - D(3)	MUG	70
	P(1,1)=P(2,3)=B(5)-B(4)	MUG	80
	P(2,2) = P(3,4) = Q(1) = D(6) - D(5)	MUG	90
	P(2,1)=P(3,3)=D(7)-D(6) P(3,2)=P(4,4)=Q(2)=D(8)-D(7)	MJG	180
		MU G	110
	P(3,1)=P(4,3)=D(9)=D(8)	MUG	120
	P(4,2)=Q(3)=D(18)+D(9)	MJG	130
	P(4,1)=D(11)-D(10)	MUG	1 40
	D12=D(9)+3.*(D(11)-D(10))	MJG	150
	Q(4)=D12-D(11)	MUG	160
	CALL INVR(P,PI,4,0,4)	MU G	170
	00 1 I=1,4	MUG	180
	A(I)=0. DO 1 J=1.4	MUG	190
4	$A(I) = A(I) + PI(I_2 \cup I) + Q(U)$	MJG	200
1	4(1)=A(1)461(1)0). (((0)	MUG	210
		MJG	220
	QUADRATIC SYNTHETIC DIVISION	MU G	230
	NUMERICAL CALCULUS	MUG	240
	W. E. MILNE PAGE 53	MUG	250
	We Estille Page 93	MUG	260
		MUG	270
	X=0 •	MUG	280
	X=0 ο Y=0 ο	MUG	290
	AD=1.	MJG	300
	A1=-A(1)	MUG	310
	A2 = -A(2)	MJG	320
	A3 = -A(3)	MUG	330
	A4=-A(4)	MUG	340
4.0	B0=A0	MJG	350
ŦÜ	81=A1-X*B0	MUG	360
	92=A2-X*B1-Y*BB	MUG	370
	83=A3*X*B2~Y*B1	MUG	380
	84 = A 4 - X + B 3 - Y + B 2	MUG	390
	CHETTER TO WE TO WE		

C	:0=B0	MJG	400
C	1=B1-X*C0	MUG	410
C	2=92-X*C1-Y*C0	MJG	420
C	3= -X*C2-Y*C1	MJG	430
D	D=C2**2-C3*C1	MUG	448
D	X= (93*C2-B4*C1)/DD	MJG	450
D	Y=(84*C2-83*C3)/DD	MUG	460
X:	=X +DX	MUG	470
Y	' <b>=∀</b> +DΥ	MUG	480
I		MUG	490
I	· · · · · · · · · · · · · · · · · · ·	MJG	500
U	=B1	MUG	510
۷:	'=82	MJG	520
E		HJG	530
I	F(ABS(ERROR).LE.0.0001) GO TO 20	MUG	540
P	RINT 100, ERROR	MJG	550
100 F	ORMAT(10X,6HERROR=,F10.7)	MUG	560
20 Q	UOT=X**2-4°*A	MUG	570
I	F(QUOT) 21,22,23	MUG	580
23 R		MJG	5 90
R	0070 V40 0000 1004 74 40	MJG	600
M	14 1 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	MUG	610
M	0140	MJG	620
	O TO 24	MJG	630
22 M	IU(1)=CMPLX(-X/2.,0.)	MUG	640
Mi	and the second of the second o	MUG	650
	0 TO 24	MUG	660
	U(1)=CMPLX (-X/2.,SQRT (-QUOT)/2.)	MJG	670
		MUG	680
		MUG	690
		MJG	700
		MUG	710
	COT4=-U/2SQRT(QUOT)/2.	MJG	720
M	U(3)=CMPEX(ROCT3,0.)	MUG	730
		MUG	740
		MUG	750
		MUG	760
		MJG	770
G	O TO 28	MUG	780

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PAGE 18	i de

25	MU(3)=CMPLX(-U/2.,SQRT(-QUOT)/2.)	aun aus	7 90
	MU(4)=CMPLX(-U/2.,-SQRT(-QUOT)/2.)	HJG	800
58	IF (AIMAG (MU(1)).EQ.O.) GO TO 30	HUG	810
	SAVE=MU(1)	NJG	820
	MU(1) = MU(3)	HUG	830
	MU(3)=SAVE	HUG	840
	SAVE=MU(2)	HU G	850
	MU(2) =MU(4)	MUG	860
	MU(4)=SAVE	HJG	870
30	CONTINUE	MU G	880
	DO 40 I=1,4	MJG	890
40	EIGEN(I)=CLOG(MU(I))*CMPLX(2.,0.)	MJG	900
	RETURN	MUG	910
	END	MJG	920

```
LIS
   SUBROUTINE LISTER (NPRINT)
                                                                             10
   COMMON /NAMES/NN(20) . PN(11) . BETAN(11) . DSTAR(11) . TFN(11)
                                                                       LIS
                                                                              20
              .PNF(51).BETANF(51).DSTARF(51).PN1F(51).BETAN1F(51).DSTLIS
                                                                              30
  2AR1F(51).PNC(51).BETANC(51).DSTARC(51).PN1C(51).BETAN1C(51).DSTAR1LIS
                                                                             40
                                                                              50
  3C(51).APN(11).ABETAN(11).ADSTAR(11).BPN(11).BBETAN(11).BDSTAR(11).LIS
  4PHIN(11)
                                                                       LIS
                                                                             60
   COMMON /PARAM/MU.EIGEN.
                                   C.NCASE.MCASE. NZ.
                                                                NPLOT. LIS
                                                                             70
                                                                       LIS
                                                                             80
  INHIST. PNFINAL. BNFINAL. DSFINAL. TIME (51) .P(4.4).Q(4)
  CCMMCN /LIMITS/PNU(51),PNL(51).BETANU(51).BETANL(51).DSTARU(51). LIS
                                                                             90
 1DSTARL(51), PN1U(51), PN1L(51), BETAN1U(51), BETAN1L(51), DSTAR1U(51), LIS 100
                                                                       LIS 110
  2DSTAR1L(51)
  CCMMON /FINAL/ PSS.BETASS.DSTARSS.DP.DR.DBETA.DPHI.A(4.4).B(4).DDELIS 120
  1LTA
                                                                       LIS 130
                                                                       LIS 140
   COMPLEX MU(4), EIGEN(4), C(5,4)
                                                                       LIS 150
   PRINT 2000
   GO TO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160,170,LIS 160
                                                                       LIS 170
  1180,190,2001,NPRINT
                                                                       LIS 180
10 CALL DATE(S)
                                                                       LIS 190
   PRINT 1000,S
   PRINT 1010, NN, MCASE, NPLOT, NHIST, PN, TPN, BETAN, TPN, DSTAR,
                                                                  TPN LÎS 200
                                                                       LIS 210
   GO TO 210
                                                                       LIS 220
20 PRINT 1020.MU.EIGEN
                                                                       LIS 230
   GO TO 210
                                                                       LIS 24B
30 PRINT 1030 MU . EIGEN
                                                                       LIS 250
   GO TO 210
                                                                       LIS 260
40 PRINT 1040, PHIN, TPN
                                                                       LIS 270
   GO TO 210
                                                                       LIS 280
50 PRINT 1050°C
                                                                       LIS 290
   GO TO 210
                                                                       LIS 300
60 PRINT 1860, MU, EIGEN, C
                                                                       LIS 310
  GO TO 210
                                                                       LIS 320
70 CONTINUE
                                                                       LIS 330
   GO TO 210
                                                                       LIS 349
80 CONTINUE
                                                                       LIS 350
  GO TO 210
90 PRINT 1090, (TIME(I), PNU(I), PNL(I), BETANU(I), BETANL(I), DSTARU(I), LIS 360
 1DSTARL(I), PN1U(I), PN1L(I), BETAN1U(I), BETAN1L(I), DSTAR1U(I), DSTAR1LLIS 370
                                                                       LIS
                                                                            380
  2(I) · I=1.51)
                                                                       LIS
                                                                            390
   GO TO 210
```

```
100 PRINT 1100, (TIME(I), PNF(I), BETANF(I), DSTARF(I), PN1F(I), BETAN1F(I), LIS
                                                                               400
                                                                          LIS 410
    10STAR1F(I) . 1=1,51)
                                                                          LIS 420
     GO TO 219
                                                                          LIS 430
 110 PRINT 1110,NZ
                                                                          LIS
                                                                               440
     GO TO 210
                                                                          LIS 450
 120 PRINT 1120. ((P(I.J). J=1.4). I=1.4)
                                                                          LIS 460
     60 TO 210
                                                                          LIS 470
 130 PRINT 1130.Q
                                                                          LIS 480
     GO TO 210
 140 PRINT 1140. (TIME(I).PNC(I). BET ANC(I).DST ARC(I).I=1.51)
                                                                          LIS 490
                                                                          LIS 500
     GO TO 210
 150 PRINT 1150, (TIME(I), PN1C(I), BETAN1C(I), DSTAR1C(I), I=1,51)
                                                                          LIS 510
                                                                          LIS 520
     GO TO 210
                                                                               530
                                                                          LIS
 160 PRINT 1160
                                                                          LIS 540
     GO TO 210
                                                                          LIS
                                                                               550
 170 PRINT 1170
                                                                          LIS 560
      GO TO 210
                                                                          LIS 570
 180 PRINT 1180
                                                                               580
                                                                          LIS
      GO TO 210
                                                                               590
                                                                          LIS
 190 CONTINUE
                                                                          LIS 600
      GO TO 210
                                                                          LIS 610
  200 CONTINUE
                                                                          LIS
                                                                              620
  210 RETURN
                                                                              630
                                                  5HD ATE=.A10 .//D
                                                                          LIS
1000 FORMAT(///, 10X,
.1010 FORMAT (10X,20 HLIST PARAMETER TABLE, 2013//5 X12H CASE NUMBER, 15,10 HLIS
                                                                               640
     1 PLOT CODE, I5, 5%, 19H TIME RESPONSE CODE, I5, //, 26%, 16 HINPUT DATA, //LIS
                                                                               650
                 ,11F9.3,/,5X,7HTIME, ,11F9.2,//,5X,7HBETAN, ,11F9.3,LIS
                                                                               660
     2.5X.7HPN.
     3/,5X,7HTIME, ,11F9.2,//,5X,7HDSTAR, ,11F9.3,/,5X,7HTIME, ,11F9.2LIS
                                                                               670
                                                                                680
                                                                          LIS
     40//)
1020 FORMAT (5X,4(4X,4HREAL, 10X,4HIMAG, 11X),//,2X,3HMU,,4(2E14,6,5X),//,LIS
                                                                                690
                                                                          LIS
                                                                               700
     12X,3HEI.,4(F10.4,4X,F10.4,9X))
 1030 FORMAT(5x.19HMU VALUES SPECIFIED.//.8x.4( 4HREAL.10x.4HIMAG.10X)LIS
                                                                                710
                             ),//,1X,6HEIGEN,,4(F10.4,4X,F10.4,4X))
                                                                          LIS
                                                                              720
     1,//,1X,3HMU,,4(2E14.6
1040 FORMAT(5 X, 264THE GENERATED PHI DATA IS., //, 5X, 7HPHIN, ,11F9. 3,
                                                                               730
                                                                          LIS
                                                                          LIS
                                                                               740
     1/,5x,7HTIME. ,11F9.2)
 1050 FORMAT (5 X, 26 HTIME RESPONSE COEFFICIENTS, // . 12 X, 5 (4 X, 4 HREAL, 6 X, 4 HIMLIS
                                                                               750
     1AG.5X),//,5X,6HPN, ,5(2F10.4,3X),//,5X.6HBETAN,,5(2F10.4,3X),//,LIS
                                                                               760
     25%,6HPHIN, ,5(2F10.4,3X).//,5%,6HDSTAR,,5(2F10.4,3X))
                                                                          LIS
                                                                               770
                                                                    ,//, LIS
                                                                               780
 1060 FCRMAT(5X,15HFITTING RESULTS,//,5X,5(11X,4HREAL,6X,4HIMAG)
```

```
15% 6HMU, 4(2F10.4.5X),//.5%.6HEIGEN..4(2F10.4.5X).//.5%.
                                                                         LIS
                                                                              7 CD
    212HCOEFFICIENTS.//.5X.6HPN. .5(2F10.4.5X).//.5X.6HBETAN..5(2F10.LIS
                                                                              800
    34.5 X).//.5X.6MPHIN. .5 (2F10.4.5X).//.5X.6HDSTAR..5(2F10.4.5X))
                                                                         LIS
                                                                              810
1070 FORMAT (5x.28HMODEL PARAMETERS-SECOND ROW. 3F10.4,5x.F10.4)
                                                                         LIS
                                                                              820
1080 FORMAT (5x, 27HMODEL PARAMETERS-THIRD ROW, 3F10. 4.5x, F10.4)
                                                                         LIS
                                                                              830
1090 FORMAT(5%,18HRESPONSE ENVELOPES,//.8x,4HTIME,12X,2HPN,13X,5HBETAN,LIS
                                                                               840
    113x, 5HDS TAR, 13x, 5HPNDOT, 10x, 8HBETANDOT, 10x, 8HD STARDOT, //, 51(3x, F9, LIS
                                                                              850
    22.12F9.3./)./]
                                                                              860
1100 FORMAT(5%.21HFITTED TIME RESPONSES.//.8%.4HTIME.8%.2HPN.5%.5HBETANLIS
                                                                              870
    1.5X.5HDSTAR,5X.5HPNDOT.2X.8HBETANDOT.2X.8HDSTARDOT.//.51(3X.F9.2.6LIS
                                                                              880
    2F10.3./)./)
                                                                         LIS
                                                                              890
1110 FO RMAT(5X.26HPAYNTERS RECIPE NUMBER IS. 16)
                                                                         LIS
                                                                              900
1120 FORMATISX.29HDIFFERENCE EQUATION P MATRIX..4F10.3./.34X.4F10.3./. LIS
                                                                              910
    134X,4F10,3,/,34X,4F10,31
                                                                         LIS
                                                                              920
1130 FORMAT (5x,29HDIFFERENCE EQUATION & VECTOR, F10.3,/,34x,F10.3,/,34xLIS
                                                                              930
    1.F10.3./.34X.F10.3)
                                                                         LIS
                                                                              941
1140 FORMATE 5X-19HINTEGRATED RESPONSE-//-8X. 4HTIME.1DX, 2HPN.7X, 5HBETALIS
                                                                              950
    1N.7K.5HDSTAR,//.51(3X.F9.2,3F12.3,/),/)
                                                                         LES
                                                                              950
1150 FORHAT(5%, 41HFIRST DERIVATIVES OF INTEGRATED RESPONSES.//.8%,4HTIMLIS 970
    1E.7X.5HPNDOT.4X.8HBETANDOT.4X.8HDSTARDOT,//.51(3X,F9.2,3F12.3,/),/LIS
                                                                             980
    21
                                                                         LIS 990
1150 FORMAT(10X.10HPN PLOTTED)
                                                                         LIS 1000
1170 FORMAT (10X, 13HBETAN PLOTTED)
                                                                         LIS 1010
1180 FORMAT(10X, 13HDSTAR PLOTTED)
                                                                         LIS 1020
2000 FORMAT(///)
                                                                         LIS 1030
     E ND
                                                                         LIS 1040
```

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SUBROUTINE GRAPHS	GRA	10
COMMON /NAMES/NN(20), PN(11), BETAN(11), DSTAR(11), TPN(11)	GR A	20
1 , PNF(51), BE TANF(51), DSTARF(51), PN1F(51), BETAN1F(51), DS		30
2AR 1F (51) , PNC (51) , BET ANC (51) , DSTARC (51) , PN1 C (51) , BETAN1 C (51) , DSTAR		40
3 C (51), APN (11), ABETAN (11), ADSTAR (11), BPN (11), BBET AN (11), BDSTAR (11)	, GRA	50
4PHIN(11)	GR A	60
COMMON / PARAM/MU, EIGEN, C, NCASE, MCASE, NZ, NPLOT,	SRA	70
1 NHIST, PNFINAL, BNFINAL, DSFINAL, TIME(51), P(4,4), G(4)	GR A	80
COMMON /LIMITS/PNU(51), PNL(51), BETANU(51), BETANL(51), OSTARU(51),		90
1DSTARL (51), PN1U(51), PN1L (51), BETAN1U(51), BETAN1L(51), DSTAR1U(51),	GRA	100
2DSTAR1L(51)	GR A	110
COMMON /FINAL/ PSS.BETASS.DSTARSS.DP.DR.DBETA.DPHI.A(4,4),B(4),DD	ESRA.	120
1LTA	GRA	130
COMPLEX MU(4), EIGEN(4), C(5,4)	GR A	140
IF(NPLOT.EQ.1) GO TO 30	GRA	150
IF(NPLCT.EQ.3) G8 TO 13	GR A	1 €0
IF(NPLOT.EQ.6) GO TO 10	GRA	170
IF(NPLOT.NE.7) GO TO 20	5RA	180
10 IF(NN(16).EQ.1) CALL LISTER(16)	G R A	190
CALL QIKSET(5.0,0.0,0.0,3.0,0.0,0.5)	AFD	200
CALL QIKPLT(TIME, PNU, 51, 14H8TIME SECONDS\$, 14H8PN 1/SECONDS\$, 11H8R	OGRA	210
1LL RATES)	GR A	220
CALL PLOT(-6.0,1.0,-3)	GR A	230
CALL QLINE(TIME, FNL, 51, 0)	SRA	240
CALL QLINE(TPN, PN, -11, 74)	GRA	250
CALL QLINE(TIME, PNF, 51, 0)	GR A	268
CALL QLINE(TIME, PNC, 51, 0)	GRA	270
CALL PLOT(-1.5,3.0,-3)	GR A	280
CALL QIKSET(5.0,0.0,0.0,3.0,-2.0,2.0)	GR A	2 90
CALL QIKPLT (TIME, PN1 U, 51, 14 H3TIME SECONDS\$, 8 H\$ CPN/DT\$, 3H\$ \$)	A S E	300
CA LL FLOT(-6.0,1.0,-3)	GR A	310
CALL QLINE(TIME, PN1L, 51,0)	G₹ A	320
CALL GLINE(TIME, PN1F, 51, 0)	GRA	330
CALL QLINE(TIME, PN1C .51,0)	GRA	340
CALL ENDPLT	G S A	350
20 CONTINUE	GRA	360
IF(NPLCT.EQ.2) GO TO 21	GRA	370
IF(NPLOT.EQ.3) GO TO 21	GS V	380
IF(NPLOT.EO.5) GO TO 21	GR A	390

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IF(NPLOT.NE.7) GC TO 30
21 IF(NN(17).EQ.1) CALL LISTER(17)
                                                               68A 400
                                                                  GRA 410
  CALL QIKSET (5.0,0.0,0.0,3.0,-5.0,4.0)
                                                                  6RA 420
  CALL QIKPLT(TIME, BET ANU. 51, 14HST THE SECONDSS, 17HSBETAN 1/SECONDSS, 32A
                                                                      430
                                                                      660
  110HSSIDESLIPS)
                                                                       450
                                                                  GRA
   CALL PLOT(-6.0.1.0.-3)
                                                                       460
                                                                  2 S A
   CALL GLINE (TIME, BETANL, 51,0)
                                                                       470
                                                                  GRA
   CALL GLINE(TIME, BETANF, 51, 0)
   CALL QLINE(TPN ,BETAN,-11,74)
                                                                       480
                                                                  GRA
                                                                      490
                                                                  G & W
   CALL OLINE(TIME, BETANC, 51,0)
                                                                  G S A
                                                                      500
   CALL QIKSET(5.0,0.0,0.0,3.0,-6.0,4.0)
                                                                  GRA 510
   CALL QIKPLT(TIME.BETAN1U.51, 14H$TIME SECONDS$, 10H$DBETA/DT$, 3H$ $1GRA 520
                                                                  GRA 530
   CALL PLOT (-6.0,1.0,-3)
                                                                  GRA 540
   CALL QLINE(TIME.BETANIL, 51, 0)
                                                                  GRA 550
   CALL QLINE(TIME, BETAN1F, 51, 0)
                                                                  GRA 560
   CALL QLINE(TIME.BETAN1C,51,0)
                                                                   GRA 570
   CALL ENDPLT
                                                                   GRA 580
30 CONTINUE
                                                                   GRA 590
   IF (NPLOT-LT-4) GO TO 40
                                                                   GRA 600
   IF(NN(18).EQ.1) CALL LISTER(18)
   CALL QIKSET (5.0.0.0.0.0.4.0,-10.0,5.0)
                                                                   GRA 610
   CALL GIKPLT(TIME, DSTARU, 51, 14HETIME SECONDSE, 17HEDSTAR 1/SECONDSE, GRA 620
  113H$LATL. CRIT.$1
                                                                   GRA 540
   CALL PLOT (-6.0.1.0.-3)
                                                                   GRA 650
   CALL QLINE(TIME.DSTARL.51.0)
                                                                   GRA 660
   CALL GLINE (TIME, DOTARF, 51,0)
                                                                   GRA
                                                                        670
   CALL QLINE(TPN .DSTAR.-11.74)
                                                                   GRA 680
   CALL QLINE(TIME, DSTARC, 51,0)
                                                                   G₹A 598
   CALL PLOT (-1.5.4.0.-3)
   CALL QIKSET(5.0,0.0,0.0,3.0,-12.0,8.0)
                                                                   GRA 700
   CALL QIKPLT (TIME, DSTAR1U, 51, 144STIME SECONDSS, 114SDDSTAR/DTS, 348 SGRA 710
                                                                   GRA 720
   11
                                                                   GRA 730
    CALL PLOT (-6.0,1.0,-3)
                                                                   GRA 740
   CALL QLINE(TIME.DSTAR11.51.0)
                                                                   GRA 750
    CALL QLINE(TIME, DSTAR1F, 51, 0)
                                                                   GRA 760
    CALL QLINE(TIME. DSTAR1C.51.0)
                                                                   57A 770
    CALL ENDPLT
```

5 5 5 5 8 8 8 8 8 6 8

40 CONTINUE RETURN END

ORIGINAL PAGE

CAS

CAS

CAS

CAS

CAS

CLS

CAS

CAS

CAS

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A O

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CAS

CAS

Cas

SUBROUTINE CASE1(NU.O. EIGEN.C)

COMPLEX 00(3.3).PPP (3).RRC(10.3)

COMPLEX A1.A2.A3.A4

DO 1 I=1.10

DO 8 I=1.4

8 C(I)=CMPLX(CC(I).CC(I+4))

C(5) = -C(1) - C(2) - C(3) - C(4)

COMPLEX 909(2.2), PPPPP(2), RRRC(10.2)

DIMENSION D(11).U(8.8).UINV(8.8).CC(8).PP(8)

DIMENSION UUU44.4). UUUINV(4.4). PPPPPPP (4).CCCC (4)

COMPLEX MU(4).DD(10).Q(4.4).P(4).RC(10.4).C(5).EIGEN(4)

DIMENSION UU (6.6).UU INV (6.6).PPPP (6).CCC(6)

CAS 400 CAS 410 CAS 420 CAS 430 CAS 440 450 CAS CAS 460 CAS 470 CAS 480 C15 490 CAS 500 CAS 510 520 CIS CAS 530 CAS 540 550 CAS CAS 560 CAS 570 CAS 580 CAS 590 CAS 600 CAS 610 CAS 620 CAS 630 CAS 640 CAS 650 CAS 660 CAS 670 CAS 680 CAS 690 CAS 700 CAS 710 CAS 720 CAS 730 CAS 740 75t CAS CAS 760 CAS 770 CAS 780

```
CAS 790
           FNTRY CASES
           A1=EIGEN (3) + (EIGEN(3) - EIGEN (2)) / (EIGEN (1) + (EIGEN (2) - EIGEN (1)))
                                                                                                                                                                                                     CAS 800
           AZ=EIGEN (4) + (EIGEN(4) - EIGEN(2))/(EIGEN(1) P (EIGEN(2) - EIGEN(1))
                                                                                                                                                                                                     CAS 810
           A3=EIGEN (3)* (EIGEN (3) -EIGEN (1))/(EIGEN (2)* (EIGEN (1) -EIGEN (2)))
                                                                                                                                                                                                     CAS 820
                                                                                                                                                                                                     CAS 830
           A4=EIGEN(4)*(EIGEN(4)-EIGEN(1))/(EIGEN(2)*(EIGEN(1)-EIGEN(2)))
                                                                                                                                                                                                     CAS 840
           DO 100 I=1.10
           RRRC(I,1)=1. +A3+A1-HU(3)++I-A3+HU(2)++I-A1+HU(1)++I
                                                                                                                                                                                                     CAS 850
                                                                                                                                                                                                     C4S 860
100 RRRC(I,2)=1.+A4+A2-MU(4) **I-A4*MU(2) **I-A2*MU(1) **I
                                                                                                                                                                                                     CAS 870
           DO 200 I=1.10
                                                                                                                                                                                                     CRS 880
200 DD (T) = CMPLX (D(I+1).0.)
                                                                                                                                                                                                     G4S 890
           00 300 I=1.2
                                                                                                                                                                                                     CAS 900
           00 300 J=1.2
                                                                                                                                                                                                     CAS 910
           .0=(L.I) 000
                                                                                                                                                                                                     CAS 920
           00 300 K=1.10
                                                                                                                                                                                                     CAS 930
300 QQQ(I,J)=QQQ(I,J)-RRR"(K,J)*RRRC(K,I)
                                                                                                                                                                                                     CAS 940
           00 400 I=1.2
                                                                                                                                                                                                     CAS 950
           PFPPP(I)=0.
                                                                                                                                                                                                     C4S 960
           DO 400 K=1.10
                                                                                                                                                                                                      CAS 970
400 PPPPP(I)=PPPPP(I)+00(K)*RRRC(K,I)
                                                                                                                                                                                                     CAS 980
           C(3) = (QQQ(2,2) * PPPPP (1) - QQQ(1,2) * PPPPPP (2)) / (QQQ(1,1) * QQQ(2,2) - QQQ(1,1) * QQQ(2,2) + QQQ(2,2
                                                                                                                                                                                                      C&S 990
         1000(1.2)*000(2.1))
           CAS 1000
                                                                                                                                                                                                      CAS 1010
        1000(1,2)*000(2,1))
                                                                                                                                                                                                      CAS 1020
            C(1)=A1*C(3)+A2*C(4)
                                                                                                                                                                                                      CAS 1030
           C(2) = A3+C(3) +A4+C(4)
                                                                                                                                                                                                      CAS 1040
           C(5) = -C(1) - C(2) - C(3) - C(4)
                                                                                                                                                                                                      CAS 1050
            RETURN
                                                                                                                                                                                                      CAS 10 60
            END
```

IIV 10 SUBROUTINE INVR(A,B,JJJ,IT, MX) INV 20 1MX,MY,MU,MS,HAT1,MAT2,HAT3,HAT4,NAT5,HAT6) PROGRAM AUTHORS R.E. FUNDERIC AND R.G. EDWARDS. INV 30 COMPUTINF TECHNOLOGY CENTER, UNICE CARBIDE CORP., NUCLEAR DIV., INV 40 INV 50 OAK RIDGE, TENN. INV €0 INV 70 CTC ORD PROGRAM NO. 9067.1 IIV 80 DIMENSION A(MX, MX), B(MX, MX) 90 INV MAT1=MX INV 100 MAT2=MX INV 110 IF (JJJ. NE. 1) GO TO 50 INV 120 B(1,1)=1./A(1,1)INV 130 RETURN IIV 140 50 CONTINUE INV 150 DO 21 I=1,JJJ INV 160 no 29 J=1.JJJ INV 170 B(I,J) = 0.0180 INV 20 CONTINUE INV 190 B(I,I)=1.0 INV 200 21 CONTINUE INV 210 KK=JJJ INV 220 LLL=VN INV 230 D=1 a INV 240 IF (JJJ.LT.0)D=0. INV 250 KKM=KK-1 14V 260 DO 9 I=1 .KKM INV 270 S=0.0 INV 280 DO 1 J=I,KK INV 290 R=ABS(A(J.I)) INV 300 IF (R.LT.S) GO TO 1 I4V 310 S=R INV 320 L∓J INV 330 1 CONTINUE 14V 340 IF (L.EQ. I) GO TO 5 INV 350 DO S J=I ,KK INV 360 S= A (I.J) INV 370 A(I,J) = A(L,J)INV 380 4(L,J)=SINV 390 2 CONTINUE

		*****	
	IF(NV.LE.0)GO TO 4	INV	400
	DO 3 J=1, NV	INV	410
	S=B(I, J)	INV	420
	B(I, J) = B(L, J)	INV	430
-	9 (L,J)=S	IVV	440
	CONTINUE	INV	450
•	0==0	IVV	460
5	IF(A(I,I).EQ.0.)GO TO 9	INV	478
	IPO=I+1	INV	480
	00 8 J=IPO,KK	INV	490
	IF (A(J, I).EQ.O.) GO TO 8	INV	500
	S=A(J, I)/A(I, I)	IAA	510
	A(J,I)=0.0	INV	520
	00 6 K=IPO,KK	IAA	530
	A(J,K) = A(J,K) - A(I,K) + S	IVV	540
6	CONTINUE	INV	550
	IF (NV.LE.0) GO TO 8	VEI	560
	DO 7 K=1.NV	IAA	570
_	B(J,K)=B(J,K)-B(I,K)*S	INV	580
	CONTINUE	INV	5 <b>90</b>
	CONTINUE	IAA	600
9	CONTINUE	INV	610
	00 10 I=1,KK	INV	620
_	D=D*A(I,I)	IAA	630
10	CONTINUE	INV	640
	IF(NV.LE.0)GO TO 13	VVI	6 <b>50</b>
	KMO=KK-1	IAA	66 <b>0</b>
	DO 12 K=1,NV	INV	670
	$B(KK_*K) = B(KK_*K) / A(KK_*KK)$	INV	680
	DO 12 I=1,KHO	INV	690
	N=KK-I	IVV	700
	DO 11 J=N,KMO	INV	710
	$8(N_9K)=B(N_9K)+A(N_9J+1)*B(J+1,K)$	INV	720
11	CONTINUE	VVI	730
	$B(N_0K)=B(N_0K)/A(N_0N)$	INV	740
	CONTINUE	VVI	750
13	DMATEQ=D	INV	760
	IF (IT.EQ.O) RETURN	INV	770
	DO 30 I=1, JJJ	INV	780
	DO 30 J=1,JJJ	VEI	790

800 810 820 830

IF (ABS(B(I,J)).LT.1.E-5)B(I,J)=0. CONTINUE RETURN END 30

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```
RES
                                                                                 10
   SUBROUTINE RESPONS
  COMMON /NAMES/NN (20) .PN(11) .BETAN(11) .DSTAR(11) .TPN(11)
                                                                                 20
                                                                          RES
              .PNF (51) .BETANF (51) .OSTARF (51) .PN1F (51) .BET AN1F (51) . OSTRES
                                                                                 30
 2AR1F(51), PNC(51), BETANC(51), DSTARC(51), PN1C(51), BETAN1C(51), DSTAR1RES
                                                                                 40
 3C(51), APN(11), ABETAN(11), ADSTAR(11), BPN(11), BBETAN(11), BDSTAR(11), RES
                                                                                 50
                                                                          RES
                                                                                 60
 4PHIN(11)
                                                                   MPLOT. RES
                                                                                 70
   COMMON / PARAM/ MU, EIGEN.
                                    C.NCASE.MCASE. NZ.
                                                                                 8.0
 1NHIST, PNFINAL, BNF INAL, DSFINAL, TIME (51), P(4,4),Q(4)
                                                                          RES
  COMMON /LIMITS/PNU(51).PNL(51).BETANU(51).BETANL(51).DSTARU(51).
                                                                                 90
                                                                          RES
 1DSTARL (51), PN1U(51), PN1L(51), BETAN1U(51), BETAN1L (51), DSTAR1U(51), RES
                                                                                100
                                                                          RES
                                                                                110
 2DSTAR1L(51)
   COMMON /FINAL/ PSS.BETASS.DSTARSS.DP.DR.DBETA.DPHI.A(4,4).B(4).DDERES
                                                                               120
                                                                          RES
                                                                                130
 1LTA
                                                                          RES 140
   COMPLEX MU(4) .EIGEN(4) .C(5,4)
                                                                          RES
                                                                                150
   DIMENSION TEMP(4,4), XTEMP(4,4), YTEMP(4,4), R(4,4)
                                                                          RES
                                                                               160
   DIMENSION XR1(51), XR2(51), XR3(51), XR4(51)
                                                                          RES
                                                                                170
   DO 1 I=1.51
                                                                          RES
                                                                                180
1 TIMF(T)=FLOAT(I-1)/10.
                                                                          RES
                                                                                190
   IF(NN(9) .EQ.1) CALL LISTER(9)
                                                                          RES
                                                                                200
  DO 10 I=1.51
   PNF (I) =C (1,1) *CEXP(EIGEN(1) *TIME(I)) +C(2.1) *CE XP(EIGEN(2) *TIME(I)) RES
                                                                                210
 1+C(3.1)*CEXP(EIGEN(3)*TIME(I))+C(4.1)*CEXP(EIGEN(4)*TIME(I))+C(5.1RES
                                                                                220
                                                                                230
                                                                          RFS
  21
   BETANF(I)=C(1,2)*CEXP(EIGEN(1)*TIME(I) )+C(2,2)*CEXP(EIGEN(2)*TIMERES
                                                                                240
 1(I))+C(3,2)*CEXP(EIGEN(3)*TIME(I))+C(4,2)*CEXP(EIGEN(4)*TIME(I))+ RES
                                                                                250
                                                                          RES
                                                                                260
  20 (5,2)
   DSTARF(I)=C(1.4)*CEXP(EIGEN(1)*TIME(I) )+C(2.4)*CEXP(EIGEN(2)*TIMERES
                                                                                270
 1(1))+C(3,4)*CEXP(EIGEN(3)*TIME(1))+C(4,4)*CEXP(EIGEN(4)*TIME(1))+ RES
                                                                                280
                                                                                290
                                                                          RES
  20 (5,4)
   PN1F(I)=EIGEN(1) *C(1,1) *CEXP(EIGEN(1) *TIME(I)) +EIGEN(2) *C(2.1)
                                                                           RES
                                                                                300
  1 +C EXP(EI GEN(2) *TIME(I)) +EIGEN(3) + C(3.1) + CE XP(E IGEN(3) +TIME(I)) +
                                                                           RES
                                                                                310
 2EIGEN(4) *C(4,1)*CEXP(EIGEN(4)*TIME(I))
                                                                           RES
                                                                                320
   BETAN1F( I) = EIGEN(1) + C( 1.2) + CEXP (EIGEN(1) + TIME (I)) + EIGEN(2) + C(2.2) RES
                                                                                330
  1+CEXP(EIGEN(2)+TIME(I))+EIGEN(3)+C(3,2)+CEXP(EIGEN(3)+TIME(I))+
                                                                                340
                                                                           RES
                                                                                350
                                                                           RES
  2EIGEN(4) *C(4,2) *CEXP(EIGEN(4) *TIME(I))
   DSTAR1F(I) = EIGEN(1) *C(1,4) *CEXP(EIGEN(1) *TIME(I)) +EIGEN(2) *C(2,4) *RES
                                                                                360
  (CEXP (EIGEN(2) *TIME(I)) + EIGEN(3) *C(3,4) *CEXP(EIGEN(3) *TIME(I)) +
                                                                          RES
                                                                                370
                                                                           RES
                                                                                380
  2EIGEN(4) *C(4,4) *CEXP(EIGEN(4)*TIME(I))
                                                                           RES
                                                                                390
10 CONTINUE
```

C

C

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IF (NN(10) .EQ.1) CALL LESTER(10)
                                                                             RES 400
  PAYNTERS RECIPE

AA=ABS(A(1))

DO 20 J=2,16

IF(ABS(A(J)).GT.ABS(AA )) AA=ABS(A(J))
                                                                             RES 410
                                                                             RES 420
                                                                             RES 430
                                                                             RES 440
                                                                             RES 450
  10 20 3-2,2

IF(ABS(A(J)).GT.ABS(AA

CONTINUE

AAT=0.1*AA

FACT=1.

DO 30 K=1.30

FACT=FACT*FLOAT(K)

X=(4.*AAT)*+K*EXP(4.*AAT)/FACT

IF(X.LT.0.001) GO TO 40
                                                                             RES 460
20 CONTINUE
                                                                             RES 470
                                                                             RES 480
                                                                             RES
                                                                                  490
                                                                             RES 500
                                                                             RES
                                                                                   510
                                                                             RES
                                                                                  520
                                                                             RES
                                                                                  530
                                                                             RES
39 N7=K+1
                                                                                   540
  IF(NN(11).EQ.1) CALL LISTER(11)
TEMP(1)=TEMP(6)=TEMP(11)=TEMP(16)=1.
TEMP(2)=TEMP(2)=TEMP(3)=TEMP(16)=1.
                                                                             RES
40 CONTINUE
                                                                                   550
                                                                             RES
                                                                                   560
                                                                             RES
                                                                                  570
   TEMP(2)=TEMP(3)=TEMP(4)=TEMP(5)=TEMP(7)=TEMP(8)=TEMP(9)=TEMP(10)=0RES
                                                                                  580
   TEMP(12)=TEMP(13)=TEMP(14)=TEMP(15)=0.
                                                                                  590
                                                                             R=S
                                                                             RES
                                                                                  600
  P(1.1)=P(2.2)=P(3.3)=P(4.4)=1.
 P(1,2)=P(1,3)=P(1,4)=P(2,1)=P(2,3)=P(2,4)=P(3,1)=P(3,2)=P(3,4)=0. RES 610
P(4,1)=P(4,2)=P(4,3)=0.
                                                                             RES
                                                                                  620
                                                                             RES
                                                                                  630
   DO 50 I=1.NZ
                                                                             RES
                                                                                  640
   DO 51 JJ=1.16
                                                                             RES
                                                                                  650
51 XTEMP(JJ)=0.0
   DO 55 J=1.4
                                                                             RES
                                                                                  660
                                                                             RES
                                                                                  670
   DD 55 K=1.4
                                                                             RES
                                                                                   680
   DO 55 L=1.4
                                                                             RES
55 XTEMP(J.K)=XTEMP(J.K)+TEMP(J.L)*A(L.K)*0.1/FLOAT(I)
                                                                                  690
                                                                             RES
                                                                                  700
   DO 52 JJ=1.16
                                                                             RES
                                                                                  710
52 TEMP(JJ) =XTEMP(JJ)
                                                                             RES 720
   00 60 II=1.16
                                                                             RES
                                                                                  730
60 P(II)=P(II)+TEMP(II)
                                                                             RES 740
50 CONTINUE
   IF(NN(12).EQ.1) CALL LISTER(12)
TEMP(1)=TEMP(6)=TEMP(11)=TEMP(16)=1.
                                                                             RES
                                                                                  750
                                                                             RES 760
   TEMP(2)=TEMP(3)=TEMP(4)=TEMP(5)=TEMP(7)=TEMP(6)=TEMP(9)=TEMP(10)=0RES
                                                                                   770
                                                                             RES
                                                                                  780
   TEMP(12)=TEMP(13)=TEMP(14)=TEMP(15)=0.
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R(1,1)=R(2,2)=R(3,3)=R(4,4)=1.
                                                                         RES 790
   R(1,2)=R(1,3)=R(1,4)=R(2,1)=R(2,3)=R(2,4)=R(3,4)=R(3,2)=R(3,4)=0 RES 800
                                                                         RES 810
   R(4,1)=R(4,2)=R(4,3)=0.
                                                                         RES 820
   DO 61 I=1.NZ
                                                                         RES 830
   00 62 JJ=1.16
                                                                         RES 840
62 XTEMP(JJ)=0.0
   DO 65 J=1.4
                                                                         RES 850
                                                                         RES
                                                                              860
   DO 55 K=1,4
                                                                        RES
                                                                              879
   DO 65 L=1.4
65 XTEMP(J.K)=XTEMP(J.K)+TEMP(J.L)+A(L.K)+0.1/FLOAT(I+1)
                                                                         RES 880
                                                                        RES 890
   DO 67 JJ=1,16
                                                                        RES 900
67 TEMP(JJ) = XTEMP(JJ)
                                                                         RES 910
   DO 69 II=1.16
69 R(II)=R(II)+TEMP(II)
                                                                        RES 920
                                                                        RES 930
61 CONTINUE
                                                                        RES 948
   Q(1) = R(1, 1) + B(1) + R(1, 2) + B(2) + R(1, 3) + B(3) + R(1, 4) + B(4)
   Q(2) = R(2,1) + B(1) + R(2,2) + B(2) + R(2,3) + B(3) + R(2,4) + B(4)
                                                                        RES 950
   Q(3) = R(3.1) + B(1) + R(3.2) + B(2) + R(3.3) + B(3) + R(3.4) + B(4)
                                                                         RES 960
   Q(4)=R(4.1)*8(1)+R(4.2)*9(2)+R(4.3)*8(3)+R(4.4)*B(4)
                                                                        RES 970
                                                                        RES 980
   Q(1)=Q(1)*0.1
                                                                         RES 990
   Q(2) = Q(2) *0.1
                                                                         RES 1000
   Q(3)=Q(3)+Q_1
                                                                        RES 1010
   Q(4) = Q(4) * Q_0 1
                                                                        RES 1020
   IF(NN(13).EQ.1) CALL LISTER(13)
                                                                        RES 1030
   XR1(1) = XR3(1) = XR4(1) = 0.
                                                                         RES 1040
   XR2(1) =- DDELTA/DR
                                                                         RES 1050
   DO 70 I=2,51
  XR1(I)=P(1,1)*XR1(I-1)+P(1,2)*XR2(I-1)+P(1,3)*XR3(I-1)+P(1,4)*XR4(RES 1060)
                                                                        RES 1070
  1T-1)+Q(1)
  XR2(I)=P(2,1)*XR1(I-1)+P(2,2)*XR2(I-1)+P(2,3)*XR3(I-1)+P(2,4)*XR4(RES 1080
                                                                         RES 1090
  11-11+0(2)
  XR3(I) = P(3,1) + XR1(I-1) + P(3,2) + XR2(I-1) + P(3,3) + XR3(I-1) + P(3,4) + XR4(RES 1100)
70 XR4(I)=P(4,1) + XR1(I-1) + P(4,2) + XR2(I-1) + P(4,3) + XR3(I-1) + P(4,4) + XR4(RES 1120
                                                                         RES 1130
  1I-11+Q(4)
                                                                         RES 1140
   DO 71 I=1.51
                                                                         RES 1150
   PNC(I)=PSS*XR1(I)
                                                                         RES 1160
   BETANC(I)=BETASS=XR3(I)
                                                                         RES 1170
71 DSTARC(I)=DP*XR1(I)+DR*XR2(I)+DBETA*XR3(I)+DPHI*XR4(I)+DDELTA
```

	IF(NN(14).EQ.1) CALL LISTER(14)		1100
		RES	1190
	DO 88 I=1,51 XR1T=XR1(I)*A(1,1)+XR2(I)*A(1,2)+XR3(I)*A(1,3)+XR4(I)*A(1,4)+B(1)	RES	1200
	XR2T=XR1(I) +A(2,1)+XR2(I)+A(2,2)+XR3(I)+A(2,3)+XR4(I)+A(2,4)+B(2)	RES	1210
	VD3 4-4 D4 4 1 1 4 A 6 3 4 1 4 4 B 2 ( 1 1 4 A 6 3 6 2 8 4 4 8 3 6 1 1 4 A 6 3 6 4 8 4 8 4 8 4 8 4 8 4 8 4 8 4 8 4 8 4	K= 2	1550
	XR4T = XR1(I) + A(4,1) + XR2(I) + A(4,2) + XR3(I) + A(4,3) + XR4(I) + A(4,4) + B(4)	RES	1230
	PN1C (I )=PSS*XR1T	<b>KF2</b>	1240
	BETANIC(I)=BETASS*XR3T	RES	1250
80	DSTAR1C(I)=DP#XR1T+DR#XR2T+DBETA#XR3T+DPHI#XR4T		1260
• •	IF(NN(15).EQ.1) CALL LISTER(15)	RES	1270
		RE S	1280
	RETURN END		1290
	ENU		



SUPPOSETANE MODEL (C.F. TGEN. PSS. BETASS. DSS .DP. DR. DBETA, DPHI. A.B	_ Man	10
208KOO LINE MODER LOCK TO LAND	HOD	20
1 DDEL TA)	HOD	30
COMPLEX C(5,4), EIGEN(4)		40
DIMENSION A(4,4).8(4). X(16), XINC(16), P(15,16), PINV(16,16), F(16).	MOD	50
1T(4,4) -AT(4,4) -H(4)	MDD	60
REAL L. L1. L2. K. I31. I32. I33. I34	D CH	70
DATA X/1.,4*0.,1.,4*0.,1.,4*0.,1./	HOD	80
READ 100 .V.L.C3. GCO. PSS. BETASS. DSS	HOD	90
PRINT 200 .V. L. C3.QCO.PSS.BETASS.DSS	MOD	100
READ 110, ITMAX, EPS1	HDD	110
PRINT 300 . ITMAX . E PS1 . X	MOD	120
K=C3*QC0	MOD	130
L1=REAL(EIGEN(1))	DCH	140
L2=REAL(EIGEN(2))	MOB	150
A3=REAL(EIGEN(3))	MOD	160
B3=AIMAG(EIGEN(3))	MOD	170
R11=REAL (C(1,1))/PSS	COM	180
R12=REAL (C(1,2))/BETASS	HOD	190
R13=REAL(C(1,3))/PSS	MOD	200
R14=REAL(C(1,4))/DSS	CCM	210
R21=REAL(C(2,1))/PSS	MOD	220
R22=REAL (C(2,2))/BETASS	COM	230
R23=REAL (C(2,3))/PSS	CCH	240
F24=REAL (C(2,4))/DSS	MOD	250
R31=REAL (C(3,1))/PSS	MOD	260
R32=REAL(C(3,2))/BETASS	HOD	270
R33=REAL (C (3, 3))/PSS	HOD	280
R34=REAL(C(3,4))/DSS	MOD	290
131=AIMAG(C(3,1))/PSS	MOD	300
I32=AIMAG(C(3,2))/BETASS	CCH	310
133=AIMAG(C(3,3))/PSS	MOD	320
134=AIMAG(C(3,4))/DSS	MOD	330
C1=V*R11	HOD	340
G2=G1*L/V	MOD	350
C3=V*R12	MDD	360
C4=C3*L/V	MOD	370
C5=V*R13	43 D	
C6=C5*L/V	MOD	
C7=(R14-K*R12)		

,			
94	C8=-V#K11*L1		
	C9=C8=L/V	MOD	
	D1=-C8	DCH	
	C10=V=R2i	MOD	
	C11=C10*L/V	MOD	
	C12=V*R22	M D D	440
1	C13=C12+L/V	MOD	450
	C14 = V + R2 3	MO D	1-
	C15=C14+L/V	MOD	470
	C16=(R24-K*R22)	OCH	480
	C17=-V*R21*L2	МОД	490
	C18=C17*L/V	MOD	500
	D2=-C17	. OCH	510
	C19=V*R31	HOD	520
	C20=C19+L/V	ОСМ	530
	C21=V*R32	O CM	540
	C22=C21+L/V	00%	550
	C23=V*R33	MOD	56 <b>0</b>
	C24=C23+L/V	DEM	570
	C25=R34=K*R32	ФСМ	580
	C26=V*(I31*B3-R31*A3)	MOD	590
	C27=C26*L/V	MOD	600
	D3= -C26	DOH	510
	C28=V*I31	MO D	620
	C29=C28*L/V	MOD	630
	C30=V* I32	O DM	640
	C31=C30*L/V	DCM	650
	C32=V* I33	MOD	660
	C33=C32*L/V	MOD	670
	C34=134-K+132	MOD	680
	C35=-V*(R31*B3+I31*A3)	DOM	690
•	C36=C35*L/V	COM	700
	04=-C35	ОСМ	7'10
	C37=V*R11+L*R11*L1	MOD	720
	C38=V*R12+L*R12*L1	DOM	730
	C39=V*R13+L*R13*L1	MO D	740
	C40=V*R11*L1	MOD	750
	C41=V*R12*L1	MOD	760
	C42=V*R13*L1	MOD	770
	A 10 A 170 FT	DCM	780

	ne_nastia_i/xo4@at 4	MOD	790
	D5=R14*L1=K*R12*L1	MOD	800
	C43=Y*R21+L*R21*L2	MJD	610
	C44=V# K22+L3R22=L2	MOD	820
	C45=V+R23+L+R23+1,2	MOD	830
	C46=V*R21*L2	MOD	840
	C47=V*R22*L2	MOD	850
	C48=V*R23*L2	MOD	860
	D6=R24*L2-K*R22*L2	MOD	870
	C49=V*R31+L*R31*A3-L*I31*B3	OCH	880
	C50=V*R32+L*R32*A3-L*I32*B3	MOD	890
	C51=V=R33+L=R33+A3-L=I33+B3	HOD	900
	C52=V*R31*A3-V*I31*B3	HOD	910
	C53=V*(R32*A3-I32*B3)	MOD	920
	C54=V+ (R33+A3-I33+B3)	MOD	930
	D7= R34*A3-I34*B3-K*R32*A3+K*I32*E3	MOD	940
	C55=V*I31+L*I31*A3+L*R31*B3	MOD	950
	C56=V* I32+L*R32*B3+L* I32*A3	MOD	960
	C57=V*I33+L*R33*B3+L*I33*A3	HOD	970
	C58=V*R31*B3+V*I31*A3	MDD	980
	C59=V* (R 32*B3+I32*A3)	שם ממא	590
	C60=V*(R33*B3+I33*A3)	MOD	
	D8=R34*B3+I34*A3-K*R32*B3-K*I32*A3		1010
	C61=R14-K#R12-V*R12*L1		1020
	C62=-L*R12*L1		1030
	D9=-C62*V/L		1040
	C63=R24-K*R22-V*L2*R22		1050
	C64=-L*L2*R22		1060
	D10=-C64*V/L		1070
	C65=R34-K*R32-V*R32*A3+V*I32*B3		1080
	C66=L*(-R32*A3+132*B3)		1090
	D11=-C66*V/L		
	C67= I34-K+I32-V+I32+A3-V+R32+B3		1100 1110
٠	C68=-L *(R32*B3+I32*A3)		
	D12=-C68*V/L		1120
	C69=-V*R13*L1		1130
	C70=C69*L/V	MUU	1140
	D13=-C69		1150 1160
	C71=-V*R 23*L2		
	C72=C71*L/V		1170 1180
	014=-C71	MUU	TTOA

	MOO	1190
612-4.4K32.M2-702.031		1200
C/4-C/3 L/V		1210
019 073		1220
G19=4 - (K33-B3-133-H3)		1230
010-019-014		1240
010015		1250
00 4 11ER-1911HAA		1260
MM-X ATE - V A		1270
NO-ALL ALOS ALE, ALS		1280
MO-ALDY ALLOY ALLE		1290
MU-ALUV ALUV ALUV		1300
MC+V(A), V(TO)-V(C) V(TC)		1310
ME = Alway Alay = Alay Alay Alay		
F(1)=C1*AA+C2*AB+C3*AC+C4*AD+C5*AE+C6*AF+C1*X(1)+C7*X(2)+C3*X(3)+	MAA	1330
-   [		
F(2)=C10+AA+C11+AB+C12+AC+C13+AD+C14+AE+C15+AF+C10+X(1)+C16+X(2)+	MUU	1350
- 11, 1/T A LOJT OL M " A LM T TOL ( " A LL OJ T O LO		
F(3)=C19*AA+C20*AB+C21*AC+C22*AD+C23*AE+C24*AF+C19*X(1)+C25*X(2)+	MO D	1370
- 10/21 A COLTOS A CALLOS A CALOS ACCIONA DE COLTOS ACCIONAS A COLTOS A COLTOS ACCIONAS A COLTOS A COL		
F(4)=C28+AA+C29+AB+C30+AC+C31+AD+C32+AE+C33+AF+C28+X(1)+C34+X(2)+	MAN	1390
1020+X(2)+025-X(4)+025-X(10)+000-X(0)-D4		1400
MM-7421. V(10) - V(2)		1410
#D=X(\), V(In) = V(0), V(II)		1420
F(5)=C1*AA+C3*AB+C5*AC+C37*X(5)+C7*X(6)+C38*X(7)+C39*X(8)+C40*X(9)	M 2 0	1430
{*U4  *A		1440
F(6)=C10*AA+C12*AB+C14*AC+C43*X(5)+C16*X(6)+C44*X(7)+C45*X(8)+C46*	MOD	1420
1 X 1 M 1 T 1 M 1 X 1 X 1 X 1 X 1 M 1 X 1 X 1 X 1 X		1460
F(7) = C19*AA+ C21*AB+ C23*AC+ C49*X (5)+C25*X (6)+C50*X(7)+C51*X(8)+C52*	MJU	19/0
		1488
F(8)=C28 +AA+C30+AB+C32+AC+C55+X(5)+C34+X(6)+C56+X(7)+C57+X(8)+C58+	MUU	1470
1% (A) 40 A 4 K (11) 40 00 . W (15) - DO		1500
MM-MIDI - MIDI - MIDI		1510
WD-MITTLY WIOL-WILL WITCH		1520
#U=X (1/1/X (U)) = X (U)/ X (#U)/		1530
F 141-67 - GRADO - MOTOG - MOTOG - NOTA -		1540
		1550
F(10)=C11*AA+C13*AB+C15*AC+C1B*X(9)+C63*X(10)+C12*X(11)+C14*X(12)+	MOD	1570
1C64*X(6) +D10	rio u	1510

```
F(11)=C20+AA+C22+AB+C24+AC+C19+X(9)+C65+X(10)+C21+X(11)+C23+X(12)+MDD 1580
1C66*X(6)-D11
                                                                        MDD 1590
 F(12)=C29-AA+C31-AB+C33-AC+C28-X(9)+C67-X(10)+C30-X(11)+C32-X(12)+MOD 1600
                                                                        MOD 1610
1 C68 + X (6) - D12
                                                                        MOD 1620
  AA= X (13) * X (10) - X (14) * X (9)
                                                                        MOD 1630
  AB = X(13) + X(6) - X(14) + X(5)
                                                                        MOD 1640
 AC=X (15) *X (10) ~X (14) *X (11)
                                                                        MOD 1650
  AD = X(15) + X(6) - X(14) + X(7)
 AE=X(16) *X(10) -X(14) *X(12)
                                                                        MOD 1660
 AF = X(16) + X(6) - X(14) + X(8)
                                                                        MOD 1670
                                                                        MDD 1688
 F(13)=C1+AA+C2+AB+C3+AC+C4+AD+C5+AE+C6+AF+C1+X(13)+C7+X(14)+C3+
                                                                        MDD 1690
1X(15)+C5+X(16)+C69+X(10)+C70+X(6)-D13
 F(14)=C10#AA+C11#AB+C12#AC+C13#AD+C14#AE+C15#AF+C10#X(13)+C16#
                                                                        MOD 1700
                                                                        MDD 1710
 F(15)=C19*AA+C20*AB+C21*AC+C22*AD+C23*AE+C24*AF+C19*X(13)+C25*
                                                                        M3D 1720
                                                                        MOD 1730
 1X(14)+C21*X(15)+C23*X(16)+C73*X(10)+C74*X(6)-D15
  F(16)=C28*AA+C29*AB+C30+AC+C31*AD+C32*AE+C.33*AF+C28*X(13)+C34*
                                                                        MOD 1740
                                                                        MOD 1750
 1x(14)+C30*x(15)+C32*x(16)+C75*x(10)+C76*X(6)=D16
                                                                        MDD 1760
  DO 5 I=1.256
                                                                        MOD 1770
5 P(I) = 0.
                                                                        MDD 1780
  P(1.1)=C1*X(10)+C2*X(6)+C1
  P(1,2) = -C1 + x(9) - C2 + x(5) - C3 + x(11) - C4 + x(7) - C5 + x(12) - C6 + x(8) + C7
                                                                        M3D 1790
                                                                        MOD 1800
  P(1.3)=C3*X(18)+C4*X(6)+C3
                                                                        MOD 1810
  P(1,4) = C5 + X(10) + C6 + X(6) + C5
                                                                        MOD 1820
  P(1,5) = -C2*X(2)
                                                                        MOD 1830
  P(1.5) =C2*X(1) +C4*X(3) +C6*X(4) +C9
                                                                        MOD 1840
  P(1,7) = -C4*X(2)
                                                                        MOD 1850
  P(1,8) = -C6 + X(2)
                                                                        MOD 1860
  P(1,9) = C1*X(2)
                                                                        MOD 1870
  P(1,10)=C1*X(1)+C3*X(3)+C5*X(4)+C8
                                                                        MOD 1880
  P(1,11) = -C3 + X(2)
                                                                        MDD 1890
  P(1,12) = -C5 + X(2)
                                                                        MOD 1900
  P(2.1) = C10 + X(10) + C11 + X(6) + C10
  P(2,2)=-C10+X(9)-C11+X(5)-C12+X(11)-C13+X(7)-C14+X(12)-C15+X(8)+ MDD 1910
                                                                        MOD 1920
 1C16
                                                                        MOD 1930
  P(2.3) = C12 \times X(10) + C13 \times X(6) + C12
                                                                        MOD 1940
  P(2,4)=C14*X(10)+C15*X(6)+C14
                                                                        MOD 1950
  P(2,5) = -C11*X(2)
                                                                        MON 1960
  P(2.6)=C11*X(1)+C13*X(3)+C15*X(4)+G18
                                                                        MOD 1970
  P(2,7) = -C13 + X(2)
```

P(2,8)=-C15*X(2)	MOD	1980
P(2,9)=-C10*X(2)	NOD	1990
P(2,18)=C10*X(1)+C12*X(3)+C14*X(4)+C17	MO D	2000
P(2,11)=-C12*X(2)	HOD	2010
P(2,12)=-C14+X(2)	MOD	2020
P(3,1)=C19*X(10)+C20*X(6)+C19	MOD	2030
P(3,2)=-C19*X(9)-C20*X(5)-C21*X(11)-C22*X(7	)-C 23*X(12)-C24*X(6)+ MOD	2040
1C 25	COM	2050
P(3,3)=C21*X(10)+C22*X(6)+C21	COM	2060
P (3,4)=C23*X (10)+C24*X(6)+C23	OCH :	2070
P(3,5)=-C20*X(2)	COM	2080
P(3,6)=C20*X(1)+C22*X(3)+C24*X(4)+C27	HOD	2090
P(3,7)=-C22*X(2)	DCH	2100
P(3,8)=-C24*X(2)	HOD	2110
P(3,9)=-C19*X(2)	MOD	2120
P(3, 10) = C19*X(1)+C21*X(3)+C23*X(4)+C26	COM	2130
P(3,11)=-C21*X(2)	MOD	2140
P(3,12) = -C23 * X(2)	MO D	2150
P(4,1)=C28*X(10)+C29*X(6)+C28	d C M	2160
P(4,2)=-C28*X(9)-C29*X(5)-C30*X(11)-C31*X(7	1-C32*X(12)-C33*X(8)+ HOD	2170
1 C34		2180
P(4,3)=C30*X(18)+C31*X(6)+C30	COM	2190
P(4,4)=C32*X(10)+C33*X(6)+C32	DOM	2200
P(4,5) = -C29 + X(2)	MOD	2210
P(4,6)=C29*X(1)+C31*X(3)+C33*X(4)+C36		2220
P(4,7) = -C31 + X(2)	COM	2230
P(4,8) = -C33 + X(2)	DOM	2240
P(4.9)=-C28*X(2)	ОСМ	2250
P(4,10) = C28 + X(1) + C30 + X(3) + C32 + X(4) + C35		2260
P(4,11) = -C30 + X(2)		2270
P(4,12)=-C32*X(2)		2280
P(5,5) =C1*X(10)+C37	DOM	2290
P(5,6)=-C1*X(9)-C3*X(11)-C5*X(12)+C7	00K	2300
P(5,7)=C3*X(10)+C38	OCM	2310
P(5,8)=C5*X(10)+C39	MOD	2320
P(5,9)=-C1*X(6)+C40	HOD	2330
P(5,10)=C1*X(5)+C3*X(7)+C5*X(8)	DOM	2340
P(5,11)=-C3*X(6)+C41	MOD	2350
P(5,12)=-C5+X(6)+C42	DOM	2360
P(6.5)=C10*X(10)+C43	GOM	2370

	MOD 2380
P(6,6) =-C10+X(9)-C12+X(11)-C14+X(12)+C16	MOD 2390
P(6,7) =C12*X(10)+C44	NOD 2400
P (6.8) = C14*X (10) 0 C45	MOD 2410
P(6,9)==C10*X(6)+C46	MDD 2420
P(6,10)=C10=X(5)+C12=X(7)+C14=X(8)	M30 2430
P(6,11)=-C12*X(6)+C47	MDD 2440
P(6, 12) = -C14 + X(6) + C48	MDD 2450
P(7,5)=C19*X(10)+C49	MDD 2460
P(7,6) = -C19 + x(9) - C21 + x(11) - C23 + x(12) + C25	MOD 2470
P(7,7)=C21*X(10)+C50	MOD 2480
P(7,8)=C23*X(10)+C51	MAD 24.00
P(7,9)==C19*X(6)+C52	MOD 2500
P(7,9)==C19*X(6)+C52 P(7,10)=C19*X(5)+C21*X(7)+C23*X(8)	MOD 2510
b 11 4 T 11 C 5 T . V 4 D 1 4 O D O	MOD 2520
P(7,12)=-C23*X(6)+C54	MDD 2530
P(8,5) =C28*X(10) + C55	MOD 2540
P(8,6) = -C28 + X(9) - C30 + X(11) - C32 + X(12) + C34	MOD 2550
P(8,7)=C30*X(10)+C56	MOD 2560
P(8,8)=C32*X(10)+C57	MOD 2570
P(8,9)=-C28*X(6)+C58	MOD 2580
P(8,10)=C28*X(5)+C30*X(7)+C32*X(8)	MQD 2590
P(8,11)=-C30*X(6)+C59	M)D 2600
P(8,12)=-C32*X(6)+C60	MOD 2610
P(9,6)=C2*X(9)+C4*X(11)+C6*X(12)+C62	MOD 2620
P(9,5) = -C2*X(10)	M3D 2630
$P(9,7) = -C4 \times X(10)$	MOD 2640
P(9,8) = -C6*X(10)	MOD 2650
P(9,9)=C2*X(6)+C1	MOD 2660
P(9,10)=-C2*X(5)-C4*X(7)-C6*X(8)+C61	MOD 2670
P(9,11)=C4*X(6)+C3	MDD 2600
P(9,12)=C6*X(6)+C5	MOD 2590
P(10,5)=-C11*X(10) P(10,6)=C11*X(9)+C13*X(11)+C15*X(12)+C64	MDD 2700
b(18*9)=C11+X(3)+C13+X(11)+C13+X(12)+C34	MOD 2710
P(10,8)=-C15*X(10)	MOD 2720
P(10,7) = -0.13 + X(10)	0575 GCM
P(10,9)=C11*X(6)+C10 P(10,10)=-C11*X(5)-C13*X(7)-C15*X(8)+C63	MOD 2740
P(1) -10) ==011 TX (5) =013 A(1) = 013 A(0) . 000	MOD 2750
P(10,11) = C13*X(6)+C12	MOD 2760
P(10,12)=C15*X(6)+C14	

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MDD 2770
      P(11.5) = -C20 * X(10)
                                                                            HOD 2780
     P(11,6)=C20*X(9)+C22*X(11)+C24*X(12)+C66
                                                                            HDD 2790
      P(11.7)==022*X(10)
                                                                            MDD 2800
      P(11.8)=-C24*X(10)
                                                                            MOD 2810
     P(11,9)=C20*X(6)+C19
                                                                            MOD 2820
P(11,10)=-C20*X(5)-C22*X(7)-C24*X(8)+C65
                                                                            MOD 2830
      P(11.11)=C22*X(6)+C21
                                                                            MDD 2840
     P(11.12) = C24*X(6) +C23
                                                                            MOD 2850
      P(12.5)=-C29*X(10)
                                                                             MDD 2860
      P(12,6)=C29*X(9)+C31*X(11)+C33*X(12)+C68
                                                                          MOD 2870
      P(12.7) = -C31 + X(10)
                                                                             MDD 2888
      P(12,8) = -C33 + X(10)
                                                                             MOD 2898
     P(12,9)=C29+X(6)+C28
                                                                             MOD 2900
     P(12,10) =-C29*X(5)-C31*X(7)-C33*X(8)+C67
                                                                             MDD 2910
     P(12,11)=C31+X(6)+C30
                                                                             MDD 2920
      P(12,12) = C33*X(6) +C32
                                                                             MDD 2930
      P(13,5)=-C2*X(14)
                                                                             MOD 2940
      P(13,6)=C2*X(13)+C4*X(15)+C6*X(16)+C70
                                                                             MOD 2950
      P(13,7) = -C4 + X(14)
                                                                             43D 2960
      P(13,8)=-C6*X(14)
                                                                             HOD 2970
      P(13,9) = -C1 + X(14)
                                                                             MDD 2989
      P(13,10)=C1*X(13)+C3*X(15)+C5* >(16)+C69
                                                                             430 2990
      P(13,11) = C3 \times (14)
                                                                             MOD 3000
      P(13,12) = -C5 + X(14)
                                                                             MDD 3010
      P(13,13) = G1 \times X(10) + C2 \times X(6) + C1
      P(13,14) =-C1+X(9) -C2+X(5) -C3+X(11) +C4+X(7) -C5+X(12) -C6+X(8)+C7
                                                                             MOD 3020
                                                                             MOD 3030
      P(13,15) = C3 + X(10) + C4 + X(6) + C3
                                                                             MOD 3040
      P(13,16)=C5*X(10)+C6*X(6)+C5
                                                                             MDD 3050
      P(14.5) = -C11*X(14)
                                                                             MOD 3060
      P(14,6)=C11*X(13)+C13*X(15)+C15*X(16)+C72
                                                                             MOD 3070
      P(14,7)=-C13*X(14)
                                                                             MDD 3080
      P(14,9) = -C10*X(14)
                                                                             MDD 3090
       P(14.8)=-C15*X(14)
                                                                             MDD 3100
      P(14.10)=C10+X(13)+C12+X(15)+C14+X(15)+C71
                                                                             MOD 3110
       P(14,11) = -C12 \times X(14)
                                                                             MOD 3120
       P(14,12) = -C14 * X(14)
                                                                              MOD 3130
       P(14.13) = C10 + X(10) + C11 + X(6) + C10
       P(14,14) =-C10*X(9)-C11*X(5)-C12*X(11)-C13*X(7)-C14*X(12)-C15*X(8)+MOD 3140
                                                                              MOD 3150
      1C15
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MOD 3160
 P(14,15) =C12*X(10)+C13*X(6)+C12
                                                                         HDD 3170
 P {14;16} = C14 = X (10) + C15 = X (6) + C14
                                                                       43D 3180
 P(15,5)=-C20*X(14)
                                                                     MOD 3190
 P(15,6)=C20*X(13)+C22*X(15)+C24*X(16)+C74
                                                                         MDD 3200
 P(15.7) =- C22 = X(14)
                                                                         MOD 3210
 P(15.8)=-C24-X(14)
                                                                         MOD 3220
  P(15,9)=-C19*X(14)
                                                                         MDD 3230
  P(15,10)=C19*X(13)+C21*X(15)+C23*X(16)+C73
                                                                         HOD 3240
  P(15,11) = -C21 * X(14)
                                                                         MOD 3250
  P(15.12) =-C23*X(14)
                                                                         MDD 3260
  P(15,13)=C19*X(10)+C20*X(6)+C19
  P(15,14) =-C19+X(9)-C20+X(5)-C21+X(11)-C22+X(7)-C23+X(12)-C24+X(8)+MJD 3270
 1 C25
                                                                         HD0 3290
  P(15,15) = C21 + X(10) + C22 + X(6) + C21
                                                                         MOD 3380
  P(15,16) = C23 + X (10) + C24 + X (6) + C23
                                                                         MOD 3310
  P(16,5)=-C29*X(14)
                                                                         MDD 3320
  P(16,6)=C29*X(13)+C31*X(15)+C33*X(16)+C76
                                                                         MOD 3330
  P(16,7) = -C31 + X(14)
                                                                         M3D 3340
  P(16,8)=-C33*X(14)
                                                                         MOD 3350
  P(15.9) = -C28 + X(14)
                                                                      MOD 3360
  P(16,18) = C28 * X (13) + C30 * X (15) + C32 * X (16) + C75
                                                                         MDD 3370
  P(16,11) =- C30 + X(14)
                                                                       MOD 3380
  P(16,12) = -C32 * X(14)
                                                                          MDD 3390
  P(15,13)=C28*X(10)+C29*X(6)+C28
  P(16,14) =- C28 * X(9) - C29 * X(5) - C30 * X(11) - C31 * X(7) - C32 * X(12) - C33 * X(8) + H30 3408
                                                                          MOD 3410
 1C34
                                                                          MOD 3420
   P(16,15)=C30*X(10)+C31*X(6)+C30
                                                                          MOD 3430
   P(16,16) =C32*X(10)+C33*X(6)+C32
                                                                          MOD 3440
 2 ITCON=1
                                                                          MOD 3450
   CALL INVR(P.PINV.16.0.16)
                                                                          MOD 3460
   DO 10 I=1.16
                                                                          MOD 3470
   XINC(I)=0.
                                                                          MOD 3480
                                                                       MOD 3490
   DO 10 J=1,16
18 XINC(I)=XINC(I)-PINV(I,J)*F(J)
                                                                       400 3500
400 3510
   00 3 I=1.16
   IF (ABS(XINC(I)) .GT. EPS1) ITCON=0
                                                                        MDD 3520
 3 \times (I) = \times (I) + \times INC(I)
                                                                        430 3530
11 CONTINUE
                                                                           MDD 3540
   IF(ITCON.NE.O) GO TO 1
```

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	CONTINUE		3550
	PRINT 500, X, XINC		3560
	GO TO 7		3570
	PRINT 400.ITER.X		3580
	CONTINUE		<b>35 90</b>
ŧ	00 6 I=1.4		3600
			3610
-	00 6 J=1.4 A(I, J)=X(4*I-4+J)		3620
ъ	DP=(V*A(3,1)+L*A(2,1))		3630
•	DR= (V*A(3,2)+L*A(2,2)+V)		3640
	DBETA=(V+A(3,3)+L+A(2,3)+K)		3650
	DPHI = (V + A (3,4)+L + A (2,4))		3660
	00 8 I=1,4		3670
	W(I) = (A(I,1) -A(I,2) +DP/DR) +REAL (C(5,1))/PSS+		3680
	L(A(I,3)-A(I,2)+DBETA/DR)+REAL(C(5,2))/BETASS+		3690
]	(A(I,4)-A(I,2)*DPHI/DR)*REAL(C(5,3))/PSS+	• •	3700
	3A(I,2)*REAL(C(5,4))/DR/DSS		3710
	W(I)==W(I)		3720
0	71=1L*A(1,2)/DR		37 30
	72=-V*A(1,2)/DR		3740
	23=-L*A(3,2)/DR		3750
	Z4=1,0V*A(3,2)/DR		3760
	B(1) = (24 + W(1) - 22 + W(3)) / (21 + 24 - 22 + 23)		3770
	B(3) = (-7.3 + W(1) + 21 + W(3)) / (21 + 7.4 - 7.2 + 7.3)		3780
	DOEL TA=(V*B(3)+L*B(1))		3790
	B(2)=W(2)+BDELTA*A(2,2)/DR		3800
	B(4) =W(4) +DDELTA*A(4,2)/DR		3810
	DP=DP*CSS		3820
	DR=DR*OSS		3830
	DRETA=DBETA*DSS		3840
	DPHI=DPHI*DSS		3850
	PRINT 900, PSS, BETASS, PSS, DP, DR, DBETA, DPHI		3850
	DDELTA=DDELTA*DSS		3870
	PRINT 800, DDELTA		3880
	PRINT 600, ((A(I, J), J=1, 4), B(I), I=1, 4)		3890
	RETURN		3900
400	FORMAT (8F18.8)		3910
100	FORMAT(14,F20.0)	MOD	3920
IIU	L OWNER TAX CORD.		

```
200 FORMAT (///.10x.44HAIRPLANE MODEL WITH SPECIFIED TIME WISTORIES.///MOD 3930
   1.10X.29HFLIGHT AND VEHICLE PARAMETERS.//.10X.6HAIRSPEED.F10.1.7H FNDD 3940
   2T/SEC. // 10X, 41HCG TO PILOT STATION LONGITUDINAL DISTANCE, F10.2, 3HHDD 3950
   3 FT. // 10x 39HDIMENSIGNAL CONSTANT FOR DSTAR EQUATION, F10. 4. 30H CUMOD 3960
   4BIC-FEET/LB-SECONDS-SQUARED, //. 10x. 16HDYNAMIC PRESSURE. F10.1.14H LMOD 3970
   5B/FT-SQUARED.//.10X.29HROLLRATE NORMALIZATION FACTOR.F10.3.//.10X.MOD 3980
   629HSIDESLIP NORMALIZATION FACTOR. F10.3.//. 10x. 26HDSTAR NORMALIZATIMOD 3990
   70N FACTOR, F10.3./)
 300 FORMAT (10x, 43HMAXIMUM NUMBER OF NEWTON-RAPHSON ITERATIONS, 18, /, 10XMJD 4010
                                              .17HCONVERGENCE LIMIT.F20.5MOD 4020
                                                                          MOD 4030
    2.//..4 X .16F8.4.//)
 400 FCRMAT (///, 10 x, 25 HITERATIONS TO CONVERGENCE, 18 .//, 10 %, 12HN-R SOLUTHOD 4040
    110N.//.4X.16F8.4.///
 500 FORMAT (10x.29HN-R SOLUTION DID NOT CONVERGE, /. 10x.19HLAST TRIAL SOMOD 4060
    1LUTION, /, 4X, 16F8, 4, /, 10 X, 24HLAST SOLUTION ADJUSTMENT, /, 4X, 16F8, 4) 43D 4070
600 FORMAT(10X, 15HTHE A MATRIX IS, 59X, 15HTHE B VECTOR IS//,4(10X, 4E16, MOD 4080
                                                                          MOD 4090
    16.10X.E16.5//))
                                                                          MOD 4100
 700 FORMAT (//.10 X.20 HMODIFIED EIGENMATRIX.//.4 (10 X.4 E20.6.//))
                                                                          MOD 4110
 800 FORMATE 10X.14H(DSTAR)DELTAA=.F20.6.///
 900 FORMAT (//.10x,19HDISTRIBUTION MATRIX.//.10x.F20.4.//.50x.F20.4.
                                                                          MDD 4120
                                                                          MOD 4130
    1//,70X,F20.4,//,10X,4E20.6,//)
                                                                          MOD 4140
1000 FORMAT(10X.4E20.6)
                                                                          MOD 4150
     END
```

# APPENDIX C Program AANDB Sample Output

### DATE= 12/01/75

Ė	IST PARAMÈTE	R TABLE :	i 1 1	1 1 1	1 1 1	1 1 1	1
CASE	NUMBER 1	PLOT CODE	0	TIME R	ESPONSE CO	DE 1	
	INP	UT DATA					
PN, Time.	0.000	•820 50	1.020	1-020	1.005	1.030	
	0.00	.50	1.00	1.50	2.00	2.50	
BETAN, Time,	0.000 0.00	.163 .50	•580 1•00	.930 1.50	.980 2.00	.800 2.50	
DSTAR,		. 376	.676	.951	1.260	1.610	
TIME,	0.00	50	1.00	1.50	2.00	2.50	

#### 9 · 9 1 1 1 1 1 1

1.070	1.090	1.075	1.045	1.025
3.00	3.50	4.00	4.50	5.00
.650	.690	。890	1.090	1.150
3.00	3.50	4.00	4.50	5.00
1.980	2.340	2.650	2.950	3.270
3.00	3.50	4.00	4.50	5.00

	REAL	IMAG	REAL	IMAG
MU,	•15943 SE+0:	i 0.	.279848E+00	O.
EI.	. 9330	0.0000	-2.5470	0.0000

REAL	IMAG	REAL	I MA G
.317662E+00	.749635E+00	•317662E+00	7 49 635E+00
4112	2.3400	4112	-2.3400

	REAL	IMAG	REAL	IMAG
MU,	•932945E+00	0 .	515220E+01	0.
EI,	1388	0.0000	3,2788	6.2832

REAL	IMAG	REAL	IMAG
.497955E+00	.781256E+00	•497955E+00	781256E+00
1528	2.0057	1528	-2.0067

ORIGINAL PAGE IS OF POOR QUALITY REAL IMAG PEAL IMAG

NU. .103636E+01 0. .392694E+00 0.

EI. .0714 0.0000 -1.8694 0.0000

REAL IMAG REAL IMAG

.256118E+00 .105674E+01 .256118E+00 -.105674E+01

.1675 2.6660 .1675 -2.6660

#### MU VALUES SPECIFIED

	REAL	IMAG	REAL	IMAG
MU.	.300517E+00	0.	.998453E+00	0 •
EIGEN	-2.4045	0.0000	0031	0.0000

REAL	IMAG	REAL	IMAG
. 451562E+00	756023E+00	• 451562E+00	.756023E+00
2543	-2.0648	2543	2.0648

THE GENERATED PHI DATA IS.

PHIN, TIME,	0.000 0.00	.247 .50	.721 1.00	1.235 1.50	1.740 2.00	2.247 2.50
		2.772 3.00	3,313 3,50	3.856 4.00	4.386 4.50	4.905 5.00

ORIGINAL PAGE IS OF POOR QUALITY

### TIME RESPONSE COEFFICIENTS

	REAL	IMAG	REAL	INAG	REAL	inag
PN.	-1.1111	0000	2.1496	.0000	.0155	.0414
BET AN .	1199	0000	-32.9159	.0000	1988	1282
Phin.	. 4435	0000	-345.4494	.0000	0190	.0034
DSTAR,	0086	0000	-215.9887	.0000	.0179	-0368

REAL	IMAG	REAL	I MA G
.0155	0 4 4 4	-1.0695	0800
1988	.1282	33.4334	0000
0190	0034	345.0439	0000
. û <b>17</b> 9	0368	215.9615	0000

## FITTING RESULTS

		*			*	
	REAL	IMAG	REAL	INAG	REAL	IMAG
HU.	.3005	0.0000	9985	0.0000	•4516	7560
EIGEN,	-2.4045	0.0000	~. 0031	0.000	2543	-2.0648
COEFFIC	IENTS				•	
PN.	-1.1111	0000	2 • 1496	.0000	.0155	.0414
BETAN,	1199	0000	-32.9159	.0000	1988	1282
PHIN,	. 4435	0000	-345.4494	.0000	0 19 O	.0034
DSTAR,	0086	0000	-215.9887	.0000	.0179	.0368
			RE&L	IMAG	REAL	IMAG
			• 4516	.7560		
			2543	2.0648		
			. Df. 55	0414	<b>-1.</b> 0695	0000
			1988	.1282	33.4334	0000
e de la companya de La companya de la co			0190	0034	345.0439	~.0000
			.0179	0368	215.9615	0000

#### AIRPLANE MODEL WITH SPECIFIED TIME HISTORIES

FLIGHT AND VEHICLE PARAMETERS

AIRSPEED 612.2 FT/SEC

CG TO PILOT STATION LONGITUDINAL DISTANCE 22.24 FT

DIMENSIONAL CONSTANT FOR DSTAR EQUATION -. 3190 CUBIC-FEET/LB-SECONDS-SQUARED

DYNAMIC PRESSURE 331.8 LB/FT-SOUARED

ROLLRATE NORMALIZATION FACTOR .500

1- SIDESLIP NORMALIZATION FACTOR 10.000

DSTAR NORMALIZATION FACTOR .010

MAXIMUM NUMBER OF NEWTON-RAPHSON ITERATIONS 50
CONVERGENCE LIMIT .000018

K 1.0000 0.0000 0.0000 0.0000 0.0000 1.0000 0.0000 0.0000 0.0000

1.0000 0.0000 0.0000 0.0000 0.0000 1.0000

N-R SOLUTION

-, 0206

9536

.0533

-. 2013

(DSTAR)DELTAA=

10.0000

--143513E+01

• 5000

.326127E+00

-.111278E+00

-.023401

#### THE A MATRIX IS

2556205-02	109390E+02	.770832E+00	235877E+01
206077E-03	.384788E+01	358690E+00	534355 E-01
•532788E-01	201315E+CO	100515E+01	.253874E-01
<u> 2627035 = 02</u>	.278157F+60	207575E-01	•959579E+00

#### THE B VECTOR IS

- .581800E+01
- +.527109E-01
- -.2151 79E+00
  - .495307E-01

#### RESPONSE ENVELOPES

TIME		PN	86	TAN	DS	TAR
0.00	0.000	0.000	2.000	-2.000	4.000	-4.000
. 10	. 333	.010	2.000	-2.000	4.000	-4.000
. 20	.667	.027	S.000	-2.000	4.000	-4.000
• 30	1.000	.065	2.000	-2.000	4.000	-4.000
• 4 0	1.043	•107	2.000	-2.000	4.000	-4.000
. 50	1.064	.160	2.000	-2.000	4.000	-4.000
.60	1.076	. 227	2.000	-2.000	4.000	-4.000
.70	1.080	• 300	2.000	-2.000	4.000	-4.000
.80	1.080	. 360	2.000	-2.000	4.400	~4.000
.90	1.078	.409	2.000	-2.000	4.000	-4.000 -4.000
1.00	1.076	. 450	2.000	-2.000 -2.000	4.000 4.000	-4.000
1.10	1.074	3 479 507	2.000	-2.000 -2.000	4.000	-4.000
1.20	1.072	• 507 530	2.000 2.000	-2.000	4.000	-4.000
1.30	1.070	•530 •556	2.000	-2.000	4.000	-4.000
1.40	1.069 1.067	• 579	5.000	-2.000	4.000	-4.0C0
1.50 1.60	1.065	.600	2.000	-2.000	4.000	-4.000
1.70	1.063	.620	2.000	-2.000	4.000	-4.000
1.80	1.061	.639	2.000	-2.000	4.000	-4.000
1.90	1.059	. 656	2.000	-2.000	4.000	-4.00ē
2.00	1.057	677	2.000	-2.000	4.000	-4.000
2.10	1.055	•692	2.100	-2.100	4.200	-4.200
2.20	1.053	.708	2.200	-2.200	4.400	-4.400
2.30	1.051	.722	2.300	-2.3[0	4.600	-4.600
2.40	1.050	.733	2.400	-2.400	4,800	-4.8CO
2.50	1.048	.748	2.500	-2.500	5.000	-5.000
2.60	1.046	. 762	2.600	-2.600	5.200	-5.200
2.70	1.044	• 778	2.700	-2.700	5.400	-5.400
2.80	1.042	.790	2.800	=2.800 =2.000	5.600	-5.600 -5.800
2.90	1.040	. 804	2.900	-2.900 -3.000	5.800 6.000	-6.000
3.00	1.038	. 816	3.000	-3.000 -3.100	6.200	-6.200
3.10	1.036	.829 .840	3.100 3.200	-3.200	6.400	-6.400
3.20 3.30	1.034 1.032	• 652	3.300	-3.300	6.600	-6.600
3.40	1.030	. 861	3.400	-3.400	6,800	-6.800
3.50	1.029	.871	3.500	-3.500	7.000	-7.000
3.60	1.027	. 880	3.600	-3.600	7.200	-7.200
3.70	1.025	.888	3.700	-3.700	7.400	-7.400
3.80	1.023	.896	3.800	-3.800	7.600	-7.600
3.90	1.021	. 90 8	3.900	-3.900	7.800	-7.800
4.00	1.019	.915	4.000	- 4. 000	8.000	-8.000
4.10	1.017	.920	4.100	-4.100	8.200	-8.200
4.20	1.015	• 929	4.200	-4.200	8,400	-8.400
4.30	1.013	. 938	4.300	-4.300	8.600	-8.600
4.40	1.011	. 947	4.400	-4.408	8.800	-8.800
4.50	1.010	.956	4.500	-4.500	9.000	-9.000
4.60	1.008	• 965	4.600	-4.600	9.200	-9.200

4.70	1.006	. 974	4.700	-4.700	9,400	-9.400
4.80	1.004	983	4.800	-4.8CD	9.600	-9.600
4.90	1.002	992	4.900	-4.980	9.800	-9.800
5.00	4.000	1.000	5.000	-5.000	10.000	-10.000

-116

PND	OT	BETAN	DOT	OSTARDOT		
4.000	.806	6.000	~6.000	12.000	-12.000 -12.000	
4.000	.711	6.000	-6.000	12.000	-9.600	
1.686	•255	4.800	-4.800	9.660	-8.300	
1.122	224	4.150	-4.150	8.300	-7.440	
. 992	- •297	3.720	-3.720 -3.200	7.446	-6.560	
. 908	323	3,280	-3.280	6.560 5.820	-5.820	
.843	<b>327</b>	2.910	-2.910	5.220	-5.220	
. 797	-,323	2.610	-2.610	4.740	-4.740	
.724	319	2.370	=2.370	4.200	-4.260	
• 663	<b>∞.304</b>	2.100	-2.100	3.900	-3.900	
• E13	289	1.950	-1.950 -1.760	3.560	-3.560	
•556	274	1.780	-1.780	3.220	-3.220	
• 5±0	251	1.610	-1.610	2.980	-2.980	
. 464	228	1.490	-1.490 -4 250	2.700	-2.700	
. 421	205	1.350	-1.350 -1.260	2.520	-2.520	
. 379	<b>183</b>	1.260		2.340	-2.340	
. 349	148	1.170	-1.170 .	2.240	-2.240	
. 318	129	1.120	-1.120 -1.070	2.140	-2.140	
.295	<b>125</b>	1.070	-1.050	2.100	-2.100	
. 272	118	1,050	-1.000	2.000	-2,000	
. 257	125	1.000	-1.000	2.000	-2.000	
. 234	÷.123	1.000	-1.000	2.000	-2.000	
• 222	121	1.000	-1.000	2.000	-2.000	
. 211	120	1,000	-1.000	5.000	-2.000	
. 199	118	1.000	-1.000	2.000	-2.000	
.192	-115	1.000	-1.000	5.000	-2.000	
. 188	114	1.000	-1.000	2.000	-2.000	
. 184	112	1.000 1.000	-1.000	2.000	-2.000	
. 1.60	110 - 400	1.000	-1.000	2.000	-2.000	
.176	109 107	1.000	-1.000	2.000	-2.000	
• 172	-	1.000	-1.000	2.000	-2.000	
.168	105 103	1.000	-1.000	2.000	-2.000	
•165	- 102	1.000	-1.000	2.000	-2.000	
. 169		1.000	-1.000	2.000	~2,000	
. 165	100 098	1.000	-1.000	2.000	-2.000	
.165	096	1.000	-1.000	2.000	-2.000	
.157 .142	095	1.000	-1.000	2.000	-2.000	
.119	<b>- •</b> 0 93	1.000	-1.000	2.000	-2.000	
.107	091	1.000	-1.000	2.000	-2.000	
.096	<b>~.</b> 089	1.000	-1.000	2.000	-2.000	
• 080	088	1.000	-1.000	2.000	-2.000	
.073	086	1.000	-1.000	2.000	-2.000	
.069	084	1.000	-1.000	2.000	-2.000	
.061	082	1.000	-1.000	2.000	-2.000	
.054	081	1.000	-1.000	2.000	-2.000	
.046	079	1.000	-1.000	2.000	-2,000	
• 046	077 077	1.000	-1.000	2.000	-2.000	
• 046 • 046	075	1.000	-1.000	2.000	-5.000	
e 17 4 0	~ (01)	44300				

.046 -.074 1.000 -1.000 2.000 -2.000 .046 -.072 1.000 -1.000 2.000 -2.000

118

### FITTED TIME RESPONSES

TIME	PN	BETAN	DSTAR	PNDOT	BETANDOT	DSTARDOT
0 • 13 ū	.000	000	000	2.828	038	672
• 10	• 252	.003	.082	2.232	.097	.832
. 20	• 450	.020	•160	1.754	• 245	.803
• 30	.606	.052	. 236	1.369		.770
• 40	. 727	. 099	.308	1.058	• 395 • 538	.736
• 50	.819	.159	. 376	. 806		.702
• 60	.889	. 231	.441	.601	。665 。769	.658
• 70	. 941	.312	504	.436	.846	.637
.80	.978	. 399	. 563	.304		•609
• 90	1.003	.489	• 621	.199	. 893	•585
1.00	1.018	.579	.677	.117	.907	. 566
1.10	1.027	. 666	.732	.055	• 890	• <b>5</b> 53
1.20	1.030	.747	.786	.009	. 843	.545
1.30	1.029	819	840	021	. 769	•542
1.40	1.026	. 881	. 895	- 040	。 671	.545
1.50	1.021	. 930	. 951	048	• 55 <b>6</b>	• 553
1.60	1.017	.966	1.009	048	. 428 20 <i>1</i>	•566
1.70	1.012	. 989	1.068	- 0 4 4 1	. 294	. 582
1.80	1.009	.998	1.129	029	.158	.601
1.90	1.005	. 995	1.192	013	.028	.621
2.00	1.006	.980	1.257	.004	~• 093 - 400	.643
2. 10	1.007	. 955	1.325	• 022	-,199	. 554
2.20	1.010	.923	1.394	.039	-•288 - 755	. 68 4
2.30	1.015	.885	1.465	• 055	= · 355	.703
2.40	2.021	. 844	1.538	.068	+。400 - 434	. 719
2.50	1.028	.802	1.611	.078	- 421	. 731
2.60	1.037	.761	1.686	.085	419 396	.741
2.70	1.045	.723	1.761	.088	~• 352	.746
2.80	1.054	.691	1.835	.087	-• 29 2	• 748
2.90	1.063	. 665	1.910	.082	-•292 ••218	.746
3.00	1.070	.648	1.983	.075	134	.741
3,10	1.077	.639	2.056	.064	045	. 733
3.20	1.083	.639	2.128	.051	.046	.722
3.30	1.087	. 648	2.198	.037		.709
3.40	1.090	. 666	2.267	.021	.135	.695
3.50	1.092	.691	2.334	.005	, 218	.680
3.60	1.091	.724	2.400	011	. 292 . 355	• 665
3.70	1.090	.762	2.464	025		.651
3.80	1.086	. 804	2.527	= .038	。403 432	.636
3.90	1.082	. 848	2.598	= 0 49	。 437	•626
4.00	1.077	. 894	2.651	058	. 454 156	.617
4.10	1.071	. 939	2.712	064	。456	.609
4. 20	1.064	. 982	2.772	-,06∓ ∞.067	. 443	.605
4.30	1.057	1.022	2.832	~.068	。416 377	•603
4.40	1.050	1.057	2.893	066	。377 320	•603
4.50	1.044	1.088	2.953	062	, 329	.606
4.6D	1.038	1.112	3.015	055	。 273 . 243	.611
	•			a U J S	。213	.617

4.70	1.033	1.130	3.077	047	. 151	.625
	1.029	1.142	3.140	037	.090	, 63 <b>4</b>
4.80		1.148	3.204	~ . 0 27	。032	.644
4.90 E.00	1.026	1.149	3.269	016	019	.654

ORIGINAL PAGE IS OP POOR QUALLIN PAYNTERS RECIPE NUMBER IS. 19

DIFFERENCE	EQUATION P	MATRIX.	.768	.117	94 <b>4</b>	003
			804	.946	.374	.001
			.003	097	• 960	•0 05
			.085	.002	021	1.000

DIFFERENCE EQUATION Q VECTOR, .528
-.011
-.020
.031

#### INTEGRATED RESPONSE

TIME	PN	BETAN	DSTAR
0.00	0.000	0.000	000
. 10	.252	.003	.082
. 20	. 450	.020	.160
. 30	e 6 0 6	.052	. 236
• 40	.727	.099	.308
.50	.819	•159	.376
.60	.889	<b>.</b> 231	.441
.70	. 9 41	。312	. 504
.80	•978	•399	.563
.90	1.003	.489	.521
1.00	1.018	579ء	.677
1.10	1.027	. 666	.732
1.20	1.030	.747	.786
1.30	1.029.	.819	.840
1.40	1.026	.881	. 895 0.54
1.50	1.021	.930	•951
1.60	1.017	.966	1.009
1.70	1.012	•989 008	1.068
1.80	1.009	,998	1.129 1.192
1.90	1.006	.995 .980	1.257
2.00	1.006	.955	1.325
2.10	1.007	.923	1.394
2.20	1.010 1.015	.885	1.465
2.30 2.40	1.021	. 844	1.538
2.50	1.028	.802	1.611
2.60	1.037	.761	1.686
2.70	1.045	.723	1.761
2.80	1.054	.691	1.835
2.90	1.063	.665	1.910
3.00	1.070	a 5 4 8	1.983
3, 10	1.077	<b>.</b> 639	2.056
3.20	1.083	.639	2.128
3.30	1.087	.648	2.198
3.40	1.090	.666	2,267
3.50	1.092	.691	2.334
3.60	1.091	0724	2.400
3.70	1.090	.762	2.464
3.80	1.085	.804	2.527
3.90	1.082	.848	2.590
4.00	1.077	. 894	2.651
4.10	1.071	.939	2.712
4.20	1.054	.982	2.772
4.30	1.057	1.022	2,832
4. 40	1.050	1.057	2.893
4.50	1.044	1.088	2.953
4. 60	1.036	1.112	3.015

ORIGINAL PAGE IN OF POOR QUALITY

4.70	1.033	1.130	3.077
4.80	1.029	1.142	3.140
4.90	1.026	1.148	3.204
5.00	1.024	1.149	3. 269

FIRST DERIVATIVES OF INTEGRATED RESPONSES

TIME	PNDOT	BETANDOT	DSTARDOT
0.00	2.828	03B	.832
. 10	2.232	.097	.803
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## APPENDIX D Listing of Program AANDB

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